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AEROSPACE
★ ★ ★ AMERICA ★ ★ ★

FUEL-FREE
SPACE TRAVEL

What it would mean and an idea for how to do it:
The EmDrive explained PAGE 16

Shaping the Future of Aerospace

FEBRUARY 2017 | A publication of the American Institute of Aeronautics and Astronautics | www.aerospaceamerica.org

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aerospaceamerica.org

AEROSPACE AMERICA

FEBRUARY 2017, VOL. 55, NO. 2

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Aerospace America (ISSN 0740-722X) is published monthly by the American Institute of Aeronautics and Astronautics, Inc., at 12700 Sunrise Valley Drive, Suite 200 Reston, VA 20191-5807 [703/264-7500]. Subscription rate is 50% of dues for AIAA members (and is not deductible therefrom). Nonmember subscription price: U.S., $200; foreign, $220. Single copies $20 each. Postmaster: Send address changes and subscription orders to address above, attention AIAA Customer Service, 703/264-7500. Periodical postage paid at Reston, Virginia, and at additional mailing offices.

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Shaping the Future of Aerospace

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Adam Hadhazy

writes about astrophysics and technology. His work has appeared in Discover and New Scientist magazines.

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Warren Ferster

is a senior analyst with the space consulting practice of The Tauri Group in Alexandria, Virginia. He was editor-in-chief of Space News, where he worked for 21 years, starting as the national affairs and policy reporter.

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is a frequent contributor to Aerospace America and is a West Coast correspondent for Space News.

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Michael Peck

writes about defense and space technology. His work has appeared in Foreign Policy Magazine, The National Interest and C4ISRNet magazine.

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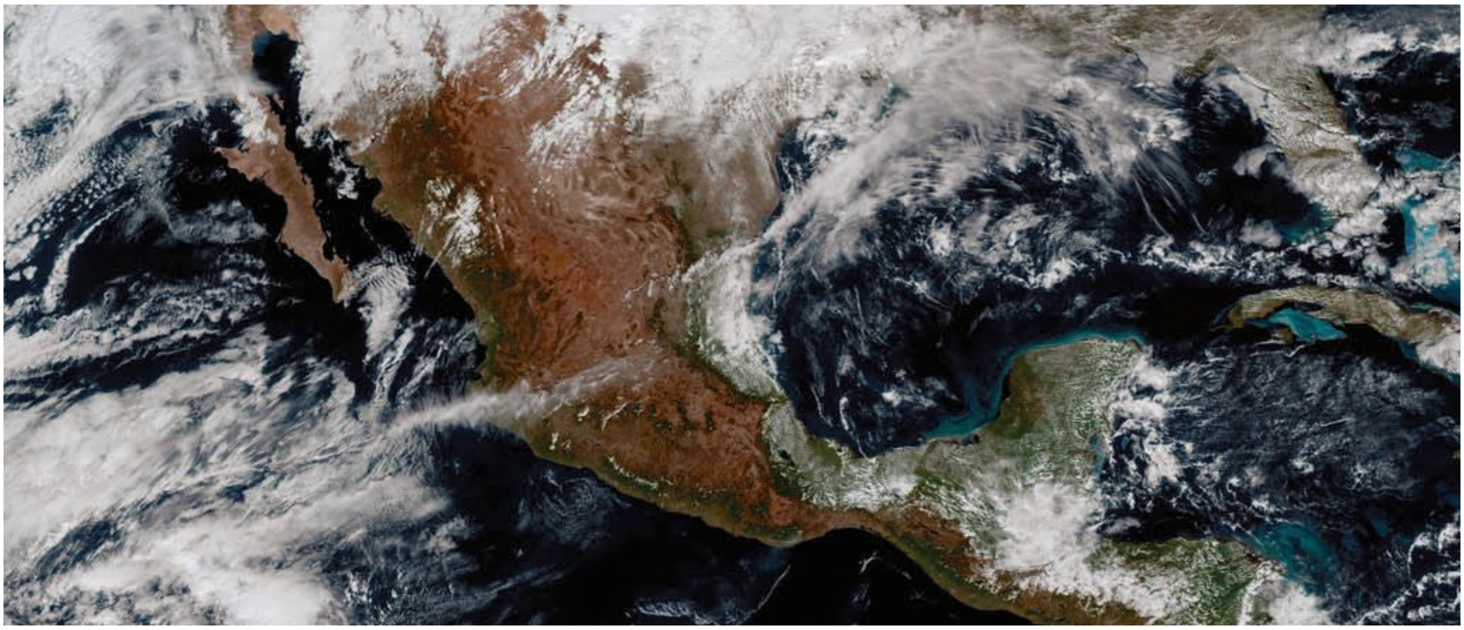
DEPARTMENTS



NASA/NOAA

On Jan. 23, NASA released this photo from the new GOES-16 satellite of a storm that brought freezing temperatures and ice to North America on Jan. 15.

The art of timeliness

When we conducted a survey of Aerospace America readers a couple of years ago, the results reinforced our strategy of focusing the magazine on timely developments relevant to AIAA's members and also the broader community.

When I'm editing, I like to imagine a notional reader. It could be someone who saw something on the TV news ticker about the launch of a revolutionary weather satellite or about a mysterious and controversial new propulsion concept. Or maybe the reader is a loyal AIAA member who knows that it's time to vote for the next AIAA president but hasn't had a chance to learn about the candidates.

Those, in fact, are among the topics you can dive into in this issue of the magazine.

For the From the Corner Office pages, I had the good fortune of interviewing the two candidates for the AIAA presidency, one of whom will start a one-year term as president-elect on May 3. One takeaway for me was that this change of leadership won't amount to simply staying the course. Each candidate has tangible, concrete proposals for reversing AIAA's membership decline. Another takeaway was that these candidates want to do that because they see a vibrant institute as necessary to empower engineers, technologists, entrepreneurs and many others to make our societies stronger.

Our cover story on the mysterious thrust measurement made at NASA Eagleworks in Houston provides the best look yet at the experiment setup and delves into the many questions about whether the measured effect was actually thrust. I don't know whether NASA's EmDrive team is onto something revolutionary. What I do know is that if the measurement turns out to be an error, that won't be an embarrassment to the research community. It would mean that the system of peer review and publishing worked as planned.

Few developments could be more timely than the arrival in geostationary orbit of a camera that can photograph cloud formations with four-times better spatial resolution than its predecessors. The atmosphere is on a warming trend, and that's likely to make storms stronger and more dangerous. Maybe even in 2017. The trick is to know which of those storms will threaten populated areas, so we can reduce false alarms. NOAA's GOES-R satellite and its Advanced Baseline Imager will help forecasters tell us that. Those stakes make the engineering challenges and budgetary twists and turns all the more interesting.

Ben

Ben Iannotta, editor-in-chief, beni@aiaa.org

YOUR AIAA PRESIDENTIAL CANDIDATES

VOTE: Feb. 6 through March 31
TERM: President-elect for one year starting May 3; becomes president in 2018 for two-year term; one-year term as past president.

Ben Iannotta interviewed John Langford on Jan. 10 and Vigor Yang on Jan. 12.

John S. Langford

POSITION: Chairman and CEO of Aurora Flight Sciences in Virginia

NOTABLE: Led development of the Daedalus human-powered aircraft as an MIT graduate student. Worked at Lockheed Martin Skunk Works in Burbank, California, for two years on what would become the F-117 stealth fighter. Founded Aurora Flight Sciences in 1989. Co-founded a spinoff, Athena Technologies, in 1998. Grew up in Georgia.

AGE: 59

RESIDES: Falls Church, Virginia

EDUCATION: Ph.D. in aeronautics and public policy from MIT, 1987; Master of Science in aeronautics and astronautics, 1984; Master of Science in defense policy, 1983; Bachelor of Science in aeronautics, 1979, all from MIT.

FAVORITE SAYING: "Never let school interfere with your education."

Declining AIAA membership >>

Membership of the AIAA has declined by a third over the last decade. In 2001, we were about 34,000, 35,000 members. [Editor's note: AIAA has 30,690 members as of Nov. 1, 2016]. It's a year-on-year almost uninterrupted decline and we have to do something about that. That is not talked about much in these meetings. The data's not hidden, but it's not addressed.

Top goal >>

If I was elected, my central focus would be: "How do we turn that [membership decline] around?" I think that's our number one key metric and that would be the focus of my term.

Untapped membership markets >>

If you look at some of the big members, they might have 2 to 5 percent of their engineers [as] members of the AIAA. Even a company like Aurora, maybe 15 to 20 percent of our engineers are members of the AIAA. So, that's a huge addressable market. There needs to be a much tighter coupling between the AIAA and the AIA [Aeropace Industries Association] and I think I know how to make that initiative get started. I can't promise that it will be successful, but there's a lot of reasons to think it would be. The second thing is you have got to reach out to the developing markets, what we call the nontraditional aerospace companies, the tech companies that have gotten into this.

Realigning >>

My experience as an entrepreneur is very relevant to the question of: "How do you realign the AIAA so that it speaks to the evolving industry?"

Ignore at your peril >>

A company in this business like Aurora sort of lives and dies on our earnings from the work that we do. A lot of the new entrants don't have to worry about earnings in aerospace. They don't even have to worry about revenues in aerospace. It's a new kind of animal, but it's a very important change to our industry and I think it's a mistake to ignore it.

Something is missing >>

The AIAA spends a lot of time trying to decide what its vision is. I am not a huge believer in spending lots and lots of time on mission statements, quite frankly. I think that success is evident when it's achieved. Our membership decline, at a time when our industry has been growing, says we are still missing something fundamental in serving the needs of our individual members and of our corporate members. The trick is going to be to find a solution set that works for the needs of both of those.

New governance structure >>

There's a lot of opportunities in it. I think the path is not totally clear about how those opportunities get realized. I had the opportunity to be on this blue-ribbon panel that made clear the need for a streamlined corporate governance process. The AIAA is a big tent. Finding a way for all of those communities to effectively work together under one corporate umbrella has been a challenge. It's a volunteer organization. It has more similarities in how it runs to a church than it does to a company like Boeing or something. ★

One of the greatest honors and privileges in my professional life was my election as President of AIAA. Helping lead this organization and chart our future together is proving to be both critically worthwhile and rewarding. Now, we have a new election on the horizon, a contest between two worthy candidates, which you, our members, must decide. Both candidates are outstanding individuals who I am sure will do much to advance the future well-being of the Institute, regardless of the outcome. I would ask you to read these candidate profiles carefully. In them, both candidates share their vision for the future and the issues they feel are important to the future health of AIAA. Their words will serve as your guideposts for the upcoming vote. As an AIAA member your fundamental right and responsibility is your vote, it is your voice on Institute affairs. When you vote, you are exercising that voice. Please do not remain silent in this election, please make your voice heard.

James Maser, AIAA President

Vigor Yang

POSITION: Chair, Georgia Tech's School of Aerospace Engineering in Atlanta

NOTABLE: Identified root cause of combustion instability in the F-1 engines of the Saturn 5 rockets, and created instability models that aid today's designers. At Georgia Tech, established a "knowledge base" with details of rocket engines, including Russian RD-180s. Organized a symposium in 1993 that saw the first extensive contacts between rocket experts from the former Soviet Union and the West. Gave the 2016 AIAA von Kármán Lecture in Astronautics. Born in Taiwan; became a U.S. citizen in 1993.

AGE: 61

RESIDES: Atlanta

EDUCATION: Ph.D. in mechanical engineering, CalTech, 1984; Master of Science in mechanical engineering, Penn State, 1980; Bachelor of Science in power mechanical engineering, National Tsing Hua University, Taiwan

FAVORITE SAYING: "Look into the future."

Diagnosing the membership decline >>

People did not see the value for them to stay on as a member. I think partly because this is a changing world. It's not just AIAA's sole responsibility. I would say it's kind of a societal issue, because aerospace engineering goes up and down. That's up to us, how to reverse the trend. For the younger generation, I think the biggest problem is the conversion from student membership to regular AIAA membership. Again, it's a matter of communications and a value proposition.

Ways to reverse the decline >>

I would say the first one is the contents. That's up to us: How to provide good service and contents. Can we offer wonderful conferences and workshops, so people come here and can learn something that will facilitate their career development? Number two is networking. Can we provide a most comfortable and effective environment to facilitate their networking? To make it short, I really think value proposition is the key to success.

Grow by reaching out >>

There are so many small firms, so many startup firms working on data security, working on autonomy, unmanned systems, and so forth. We need to reach out. I have been a professor at big public universities, Penn State and Georgia Tech. We are obliged to reach out [to] every citizen in the state, and also at the same time, to provide education to citizens with all backgrounds. That essentially resonates with the mission of AIAA.

How far can AIAA rebound?

I think there's a very, very good chance that we can grow by 25 percent in the next three years. The basis is the following: We have almost a half million workforce in aerospace and the defense industries in the U.S. I [also] see tremendous room for us to grow in other parts of the world.

Focusing on students and resource expansion >>

If I became the next president, I really want to work with our colleagues to make sure that every single aerospace engineering student in the U.S., by default, is an AIAA member. Then the next thing is: How to make it happen? Well, that requires a resource. I will personally visit all the corporate members and others, because resource expansion is a key.

Publication proposal >>

I would like to revive our AIAA student journal, because that has stopped some time ago. This time, I don't think we need a print version. We should do it electronically. AIAA should provide the infrastructure, the resource, and some fundamental guiding principles. And then after that, it's all students.

Converting students to professional members >>

We can provide a kind of a source of inspiration. Mentorship is another key. If we can provide more opportunities to facilitate a sort of a match-up, even remotely or even virtually, to pair our younger colleagues with senior colleagues, that would be wonderful. By the way, AIAA has been doing that, and we have accomplished [that] to a certain extent. I want to make it more effective.

Governance changes >>

The new governance [structure] would provide opportunities to make AIAA much more efficient, much more efficient in several areas. First one is at the operation level. That will make the AIAA operation much more efficient. Also at the same time, that will put AIAA into such a position to explore new opportunities, and also at the same time to exercise influence. ★

Forum Highlights

NASA's far-out space concepts

Imagine a rover on the surface of Venus, propelled by the slow movement of the planet's thick atmosphere; or a submarine exploring the depths of a hydrocarbon lake on Saturn's moon Titan; or maybe a lander hopping from site to site on Neptune's moon Triton; or how about a gram-sized spacecraft accelerating to 160 million kph and whizzing past an intriguing planet discovered in the solar system closest to ours.

NASA sets aside a small fraction of its $19 billion annual budget to fund studies of radical-sounding concepts like these. Panelists discussed some of the NASA Innovative Advanced Concepts program's projects.

Mason Peck, a Cornell University associate professor involved with the NIAC-supported interstellar Breakthrough Starshot Project, said NIAC is extremely valuable for those with big but high-risk visions, AIAA's Ben Iannotta reported.

He and the Breakthrough team are trying to figure out how to squeeze a spacecraft's critical elements, especially a communications package, onto what looks like a computer chip. They'll then accelerate this toward Proxima b, a recently discovered planet more than 4 light years away, by focusing laser light onto a sail.

The big question: "Can you make something small enough that also survives? We're talking about a 1 gram satellite," Peck said.

Closer to home, there is the second planet from our sun. "Venus is a fascinating planet," said Jonathan Sauder of the NASA-funded Jet Propulsion Laboratory. He wants to figure out how to navigate a rover across its surface despite pressures that would crush a nuclear submarine and temperatures that would melt lead.

At Venus' average temperature of 462 degrees Celsius, even electronics built to U.S. military specifications could not survive, because they're designed for a maximum of 125 C.

"The longest we've been able to have an object survive on Venus is two hours," he said.

So, game over? Not quite. Sauder has been studying how to make a rover operate almost entirely mechanically. On the top of the rover would be a turbine through which Venus' slow-moving, thick atmosphere would flow and propel the rover.

— Ben Iannotta | beni@aiaa.org

"I was taught the job is never finished until you've got all the data, you've analyzed the data, and you've answered all the questions."

– **Delma Freeman,** former director of NASA's Langley Research Center

"It's a period of delicious chaos … it's like a combination of the first day of school and the French revolution."

– **Dorothy Robyn,** independent consultant and writer, on presidential transitions

Wild ideas for stopping climate change

AIAA

▲ **Rutgers University's Martin Bunzl** was among panelists who said efforts to stop climate change are inadequate.

If humanity wants to get serious about eradicating human-caused climate change, it's going to have to actively intervene in the functioning of the atmosphere.

Exactly how is the question. Perhaps sulfur dioxide could be dispersed in the stratosphere to reflect solar radiation. Or carbon dioxide could be captured from the air on a vast scale. Or maybe giant sunshades could be erected in space to cool Earth.

Such geoengineering might sound extreme, but according to some scientists, active intervention is the only way to stave off a planetary warming of more than 1.5 to 2 degrees Celsius, the threshold beyond which increases in sea level could be severe.

"It is a controversial topic," said Marty Bradley, a technical fellow at Boeing and the session moderator for "Geoengineering to Mitigate Climate Change — Is There a Role for Aerospace?"

Douglas MacMartin, a geoengineering theorist at CalTech, believes that adopting renewable energy and improving efficiency would not be enough to stop profound climate change.

MacMartin said it would be possible to cool the planet rapidly, by "dumping crap" in the stratosphere in what's called solar geoengineering or sometimes solar radiation management. The idea would be to mimic the effect of the 1991 eruption of Mount Pinatubo in the Philippines, which spewed tons of sulfur dioxide into the stratosphere and cooled the planet by half a degree Celsius.

MacMartin cautioned against jumping quickly to solar geoengineering, because it could have consequences that scientists do not yet understand.

— Ben Iannotta | beni@aiaa.org

In January, over 3,700 attendees representing government, academia and industry gathered at the 2017 AIAA SciTech Forum in Grapevine, Texas.

Younger workforce is aerospace's future

Despite its bright future, the aerospace industry faces challenges in attracting and retaining younger talent.

One challenge is the low retirement rate in the aerospace industry because job movement is key for young professionals, said Graham Warwick, technology managing editor at Aviation Week & Space Technology, during a panel discussion on the aerospace industry's workforce requirements.

"It's a means to an end for them, to develop skills and advance," he said.

Warwick cited an industry workforce study that showed aerospace is still a desirable field and noted it's important for leaders to understand and address the expectations of younger employees.

In regards to progressing in today's world of rapid innovation, Curt Carlson, founder and CEO of The Practice of Innovation, said, "You need to have an environment that's open, transparent and where intense learning takes place all the time."

Representing young professionals on the panel, Ben Marchionna, lead systems integration and test engineer at SkySpecs, said he doesn't necessarily believe millennials require a purpose to energize them.

"Ultimately … millennials get excited by this idea of getting a group of really motivated people together and solving some insurmountable challenge, particularly when everyone else thinks it can't be done," he said. "They get really excited about that — and this is what's it's all about for millennials."

Jaiwon Shin, associate administrator for NASA's Aeronautics Research Mission Directorate, said one of the major opportunities at hand is bringing together all of the "seemingly disparate technologies, like autonomy, electric power management systems and communications."

Shin echoed his fellow panelists' belief that it's important to communicate to the younger generation that aviation and the aerospace industry are not dying or boring.

"I think it's just a matter of packaging things right," he said, adding that it's important for the younger generation to understand the aerospace industry is growing and could change society in a "very transformational way."

— Lawrence Garrett | lawrenceg@aiaa.org

"Every day, every night, the robots are placing [items] and doing work."

– **Dava Newman,** deputy NASA administrator, on robots working aboard the International Space Station

"We can no longer ignore AFC (Adaptive Flow Control)."

– **Israel J. Wygnanski,** University of Arizona

"You need to have an environment that's open, transparent and where intense learning takes place all the time."

– **Curt Carlson,** founder and CEO of The Practice of Innovation

Robots strike out on their own

Machines are capable of doing more with less input from humans and will soon be able to assemble other structures or machines, inevitably opening up new possibilities for aerospace.

"We're at the dawn of what a lot of people call an autonomy revolution," Danette Allen, senior technologist for intelligent flight systems at NASA's Langley Research Center, said during a panel discussion about how autonomous machines will enhance aerospace capabililites. "When we talk about these systems that learn, when we talk about these systems that adapt, we are changing the way we talk about the way humans interact with these machines."

▼ **Danette Allen,** senior technologist for intelligent flight systems at NASA's Langley Research Center, said autonomy is altering aerospace.

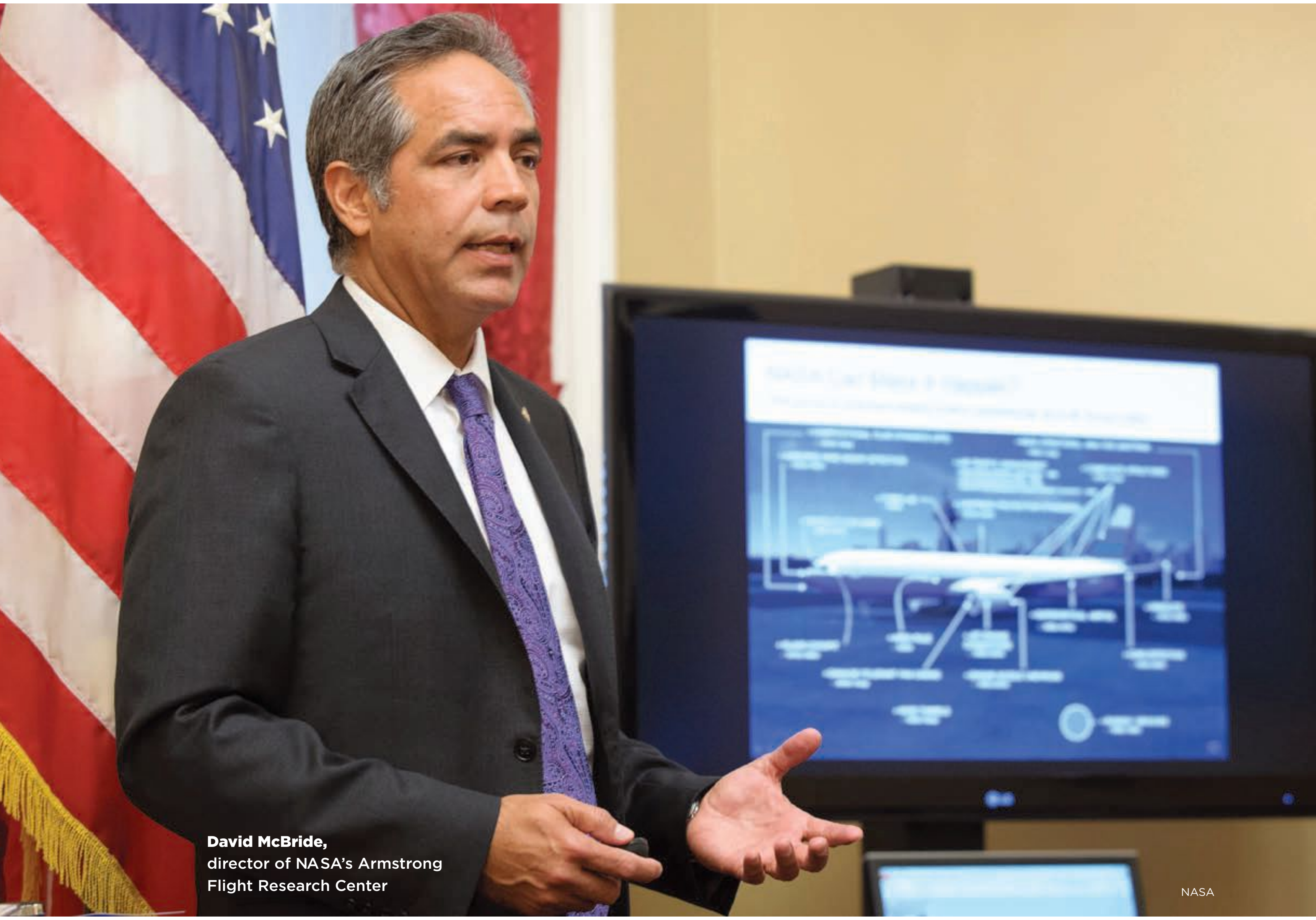
AIAA

"A lot of this stuff is spinning in from our mobile devices, speech recognition … from gaming, we've got gesture recognition," said Rob High, IBM Fellow and vice president and chief technology officer of IBM Watson. "It is our firm belief that cognitive computing will have its greatest value and most disruptive benefit when we use it to amplify human cognition."

In regards to the impact on aerospace, MIT's Neil Gershenfeld said automation and robotics could lead to self-assembling structures. He added that future space explorers could use automation to build habitats.

"An ensemble of little robots can build scalable big structures," he explained. "To make large-scale space structures, you can flat-pack them and have a little ensemble of assemblers with the flat-pack structure that then scales to a big thing."

— Hannah Thoreson | hannaht@aiaa.org



David McBride, director of NASA's Armstrong Flight Research Center

NASA

At the center of the X-plane revival

Read an edited transcript at aerospace america.aiaa.org

The first part of David McBride's nearly four-decade career at NASA's Armstrong (formerly Dryden) Flight Research Center in California centered on X-planes, but then in the early 2000s the pace of that work slowed. These days, McBride's 550 civil servants and 600 contractors are preparing for a resurgence in X-plane flights for everything from quiet supersonic transportation to electric propulsion, all under NASA's New Aviation Horizons initiative. As exciting as the X-planes are, they are not the only thing Armstrong does. The center leases an old B-1 assembly facility at Plant 42 in Palmdale from which it flies conventionally piloted science aircraft. I spoke to McBride by phone from his California office.
— *Ben Iannotta*

DAVID D. MCBRIDE

POSITION: Director of NASA's Armstrong Flight Research Center in California since January 2010.

NOTABLE: Began working at NASA's Dryden Flight Research Center (now Armstrong) in 1982 as a co-operative education student from the University of New Mexico. Was lead flight systems engineer in the 1990s for NASA's X-29 forward swept-wing aircraft. Worked on X-33 and X-31 programs.

AGE: 57

RESIDENCE: Lancaster, California

EDUCATION: Bachelor of Science in electrical engineering and Master of Business Administration, both from University of New Mexico

X-plane revival

We've had a quiet time in NASA aeronautics research over the last decade, since probably 2004. Over that 12 years, we have continued to work on maturing technologies through ground tests and wind tunnel and CFD work. Now it's time to pull some of those technologies together, or they're maturing to the point where we're ready to go to flight. The only true way to validate aeronautics technology, in my opinion, is ultimately through flight. To date, there's never been an airplane that has flown exactly as designed. That's what Armstrong's role is: to figure out what's different from design to actual flight.

X-plane planning

What's exciting now is we're going back into that [X-plane] era with the New Aviation Horizons program that [President Barack Obama] announced last year. We're kicking off with the X-57 Maxwell [electric research plane], which is going to be flown here soon, and the Low-Boom Flight Demonstrator that's in the PDR [preliminary design review] phase, right now.

The promise of quiet supersonic flight

We believe we have the basic fundamentals of understanding of supersonic flight physics and aerodynamics and atmospheric flight conditions that we can design and develop a supersonic aircraft that would reduce the sonic boom to the ground to the point where it's not a nuisance, but acceptable to the public, which would open the market for [passenger] supersonic flight.

Subsonic innovations

We've been working on things like flying the X-48 Hybrid Wing Body aircraft over the last decade in a subscale model. Now we believe, through the subscale model, we've validated some of the drag and noise benefits of the vehicle, and it's ready to go build an efficient subsonic aircraft.

Optimal development process

I believe you need all three components: CFD, wind tunnel, and flight to get a better end product.

Why X-planes benefit from pilots aboard

In a lot of cases, it's easier to have a pilot who understands aircraft dynamics and aircraft feel and can fly it. The human brain is still the best computer we have for flying an airplane. Having a man in the loop, in a lot of cases, is a cost savings. Something we've been doing for 70 years here at the center is testing handling qualities. Ultimately, as these aircraft, whether supersonic or subsonic, become transports for people, somebody has to evaluate the ride characteristics in turbulent weather, in adverse conditions, and say, ªYeah, that is acceptable for either a high-performance, high-g military type aircraft, or that's a comfortable airline that you'd be happy to put grandma and your kids on.º

"I believe that we are seeing changes in climate, and we are seeing adverse impacts to the country and to the world in regards to climate. NASA's role is to gather data on that change, on the mechanisms for the change so the policymakers ... have the data to make appropriate decisions on how to make changes and apply resources of the country."

Future of "green" aviation

Green also means less fuel burn, which means less operating cost for the airline. Although jet fuel is cheap, today, it won't stay that way forever. Operating cost and operating efficiency and the maintenance efficiency is always going to be a driver in selecting your next-generation airframe. Plus, if we take the lead in building them, and we hopefully build them here, it means jobs in the United States. That is very much in alignment with this next administration.

Earth sciences and climate change

NASA's role isn't to drive policy. What we do is we gather data. I believe that we are seeing changes in climate, and we are seeing adverse impacts to the country and to the world in regards to climate. NASA's role is to gather data on that change, on the mechanisms for the change so the policymakers, be that Congress or the executive branch of the government, have the data to make appropriate decisions on how to make changes and apply resources of the country.

Science aircraft

Our role here at the center is complex systems integration to flight. We've supported NASA science with the integration and flight of the SOFIA [Stratospheric Observatory for Infrared Astronomy], which is the 747SP with a 20-ton, 2.7-meter infrared telescope that opens to the atmosphere. That airplane has a 20-year planned life on it. We're about six years into that. It is now in routine flight operations. It flies three or four nights a week doing infrared astrophysics, both in the Northern and Southern hemispheres.

Testing space vehicles

We are working with supporting Sierra Nevada with Dream Chaser. They're scheduled to be out here in the next couple months to do another approach and landing test. If there ever is another vehicle like the shuttle or like Dream Chaser is now, with wings and landing gear, it undoubtedly would be evaluated and tested here.

Cooperative education

Every year over the summer, we usually have about a hundred interns, co-ops, summer students that come through the system. Not all of them are [in Armstrong's] Pathways Programs, but through all the different student intern programs. We work closely with AIAA in a lot of the student work that you all do, encouraging people to apply for the NASA internship programs here at the center and throughout the agency. ★

Tiny drones, big questions

The U.S. Army might someday equip troops with tiny drones that they can release from the palms of their hands. To make that possible, something other than traditional quadcopters and mini-helicopters might be required due to the rigors of military operations. Keith Button looks at two options.

By Keith Button
buttonkeith@gmail.com

For researchers building what could be the world's smallest cyclocopter — a drone powered by two spinning paddle-wheel-like cyclorotors — every gram counts. The edges of each of the craft's eight rotor blades were made by hand-laying hair-thin carbon fiber strands preimpregnated with epoxy into a Teflon mold, along with a 0.7-millimeter-thick carbon rod for the center of the frame. Then they were baked in an oven at about 175 degrees Celsius. The frames were wrapped in 5-micron-thick sheets of Mylar, the thinnest available, to create surface area.

Each rotor assembly had to weigh the equivalent of five Tic Tac breath mints or 2.5 grams, with each of the four blades on a rotor accounting for just .12 gram. The total vehicle weight came in at just 29 grams.

"Coming up with this fabrication tech-

nique and making this ultralight blade, that was a huge challenge," says Moble Benedict, a Texas A&M University assistant professor who advised two of his aerospace engineering Ph.D. students, Carl Runco and David Coleman at the Advanced Vertical Flight Laboratory, in designing and building the drone. Building super-light blades "was the only way we were going to scale this thing down."

Benedict and his teammates at Texas A&M started flying the miniature cyclocopter in December 2015 and have continued testing the design under a U.S. Army program. Benedict and collaborators at the University of Maryland had flown larger versions weighing 800, 500, 235, 210 and 60 grams over the preceding 10 years. Knowing that cyclocopters might not be the only answer for miniature flight, Benedict and Coleman also began flying a 62-gram flapping drone, dubbed the Robotic Hummingbird, for the Army in 2015.

They want to find the best solution to a deadly problem soldiers faced in Afghanistan, and one that's likely to come up in other locations where urban canyons and forest canopies play the role of mountains. Soldiers in Afghanistan would get pinned down in a valley with limited knowledge of what might lie over the next ridge and with only a tenuous communications link to commanders. By pulling a cyclocopter or a flapping drone from a rucksack and letting it fly from the palm of his or her hand, a soldier of the future would gain a bird's eye view with the aid of a 1- or 2-gram camera or the ability to relay communications via a network of other drones.

For aircraft technologists, questions abound, from which drone concept would work best in which circumstances to how cyclocopters and flapping drones would perform compared to conventional quadcopters and miniature helicopters, especially when faced with the great bane of all micro air vehicles: wind gusts.

The U.S. Army hopes to answer those questions under a program called MAST, short for Micro Autonomous Systems and Technology, which is based at the Army Research Laboratory in Adelphi, Maryland, and is set to wind down this year. MAST pays universities and companies to develop miniature ground and flying robots that could pay off in 10 to 30 years for soldiers in the field. Concepts funded under MAST include navigation sensors and joint robotic mapping schemes, perching mechanics and adhesives, alternative energy sources for micro vehicles, quadcopters, ducted-rotor aircraft, fixed-wing aircraft with wings that can lengthen or shrink, bee-sized flapping fliers and also Benedict's cyclocopter and flapping-wing aircraft. The main purpose of MAST is to identify particular modes of propulsion worthy of further research, but the Army is also curious about the comparisons among the craft.

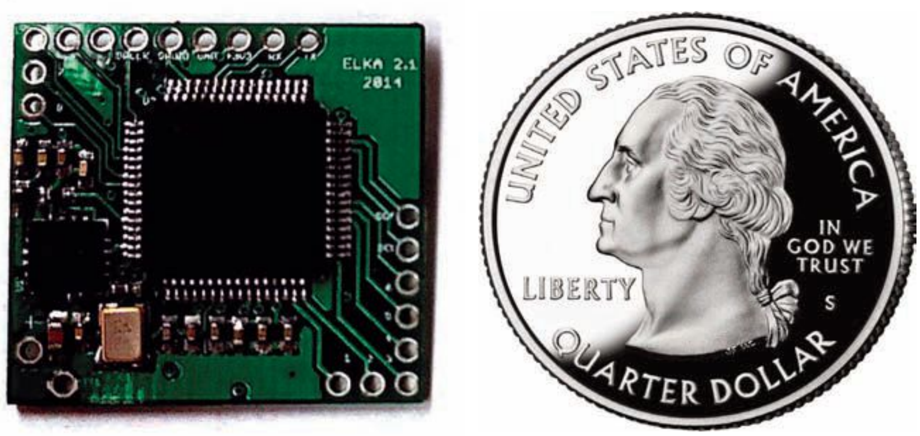
"Can these alternative configurations be more efficient; can they be more agile? You can start to ask questions like: 'Is it useful to me to have it flapping because it looks like a bird; does that add some benefit?'" says Chris Kroninger, the microsystem mechanics team leader at the Army Research Lab.

The Army program ends in September though Benedict and his team plan to continue their research on micro aircraft.

Beating the wind

The cyclocopter produces lift and horizontal movement from the spinning cyclorotors, each with four blades that tilt to 45 degrees of lift at the top and bottom of their cycles (12 and 6 on the clock) and to 0 degrees at 9 and 3. The tail rotor is a traditional-looking propeller that spins facing up to control pitch.

The flapping-wing drone has two nearly rectangular but slightly pointed wings that flap 22 times per second, controlling its hover and horizontal movements. The wings are translucent.



Vikram Hrishikeshavan/University of Maryland

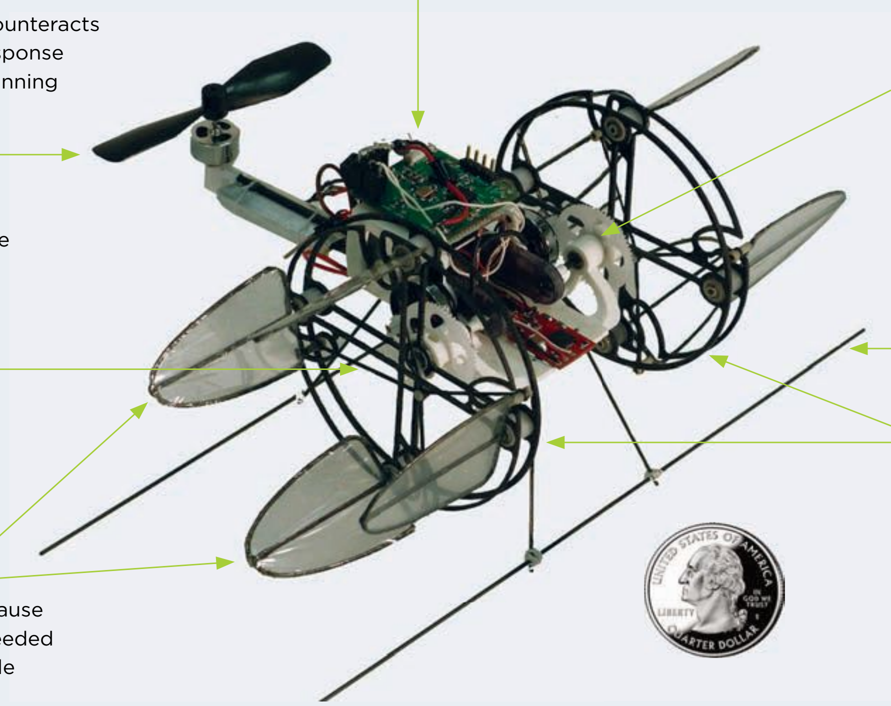
▲ **The cyclocopter's 1.3-gram autopilot sensor** board has a microprocessor, accelerometer, gyroscope and wireless communication.

Testing of the flapping and cyclocopter designs will culminate in August 2017, likely at the Army Research Laboratory in Maryland with the micro drones demonstrating hovering, flying forward and performing basic maneuvers. The researchers are also testing how fast the drones can fly, how quickly they can maneuver and how they fly when hit by simulated wind gusts from a fan, Benedict says.

Because of the obstacles that tiny drones encounter, they are likely to be always moving and adjusting their flight, so they must be agile, Kroninger says.

"We're interested in getting down in the urban canyon; we're interested in moving under the canopy; the sorts of places where soldiers operate. In those spaces, you've got gusts and wind disturbances that are on length scales that are the size of the vehicles," he says, plus the tiny aircraft have to adjust to the change in aerodynamic forces that occur close to the

29-GRAM CYCLOCOPTER



Moble Benedict/Texas A&M University

ground. "Also, there's an equivalent wall effect: If you get too close to a tree, it will pull you in. So you need an aircraft that's intrinsically agile, and you're not going to do much steady flight at these small scales."

Wind gusts are tricky for miniature unmanned aircraft, because as the size of an aircraft is scaled down, its aerodynamic force will drop by the size decrease squared, while its inertia will drop by the size decrease to the fifth power, Benedict says. That's why a manned helicopter is fine flying through 10- to 15-meter-per-second wind gusts, while a toy helicopter can't fly through 2-meter-per-second gusts.

Insects and hummingbirds can maneuver through wind gusts, and their flapping-wing flight dynamics may hold the key to why that is possible, Benedict says.

Traditional spinning helicopter rotors can be more efficient than flapping wings, producing steady air flows, but they can also fail to produce lift when that air flow is interrupted by a wind gust, he explains. The hummingbird's flapping wings produce an extremely unsteady flow field, and they're better able to create lift even when hit by a gust. Each wing creates a leading-edge vortex, or a small whirlwind sitting on top of the wing, which is an area of extreme low pressure that enhances lift. The bird, and flapping-wing insects, can keep these vortices stable on the wing.

Hummingbirds — at the end of their wing stroke — can time their wing rotation to produce either an upward or downward force and can reverse the pitch of their wing to produce upward thrust on both the downstroke and upstroke, Benedict says. The birds' wings can also capture energy from the wake of a previous wing stroke, and hummingbirds can actively control their pitch, roll and yaw, and make adjustments based on their sensing the wind or the flow field on their wings.

Flight control

Flapping-wing drones are worth studying because of their agility and wind gust tolerance, though not for efficiency, Benedict says. The flapping-wing drone controls its flight path and its hover like a hummingbird would: by changing the length of one wing's stroke relative to the other wing to control roll, by tilting forward both planes of flapping to change pitch, and by tilting one wing's plane forward and the other plane back to change yaw.

One challenge with both cyclocopters and flapping-wing aircraft is their inherent instability. The blades on a cyclorotor are always changing angles, so the aerodynamics are unsteady and changing over time. A 1.3-gram autopilot, designed at the University of Maryland by Vikram Hrishikeshavan and Inderjit Chopra, controls both the 29-gram cyclocopter and the 62-gram robotic hummingbird with a microprocessor connected to a triaxial gyro-

Scaling up tiny designs

Suspecting that smaller might not always be better when it comes to drones, researchers at Texas A&M University are also starting to study the merits of scaling up flapping-wing and cyclocopter concepts for larger unmanned aircraft for a program sponsored by the Army, Navy and NASA at the Vertical Lift Research Center of Excellence at the University of Maryland. The Texas A&M contract with the sponsors runs into 2021.

On the cyclocopter side, they will build and test larger drones to see how they perform as they scale up, how they compare to conventional helicopters, if they become any more efficient and if they can improve their rotor weight to total vehicle weight ratio. Moble Benedict, a Texas A&M assistant professor, says he believes cyclocopters could even be viable as small manned aircraft.

For the flapping-wing research, Benedict and his team will build a single 10- to 15-gram flapping wing in about six months Ð not the whole aircraft Ð to project how a 1.6-kilogram hovering drone might fare, and to see what the key barriers would be to scaling up a hover-capable flapping drone. For Benedict, the key question is: Why in nature can only insects and small birds hover, and not the larger birds? If it's just a muscle scaling issue, then prospects for larger flapping-wing drones would be bright because the researchers could easily scale up motors.

Among hummingbirds, the best fliers weigh about 3 grams. Hummingbirds as large as 20 grams do exist, but they are lousy fliers, Benedict says.

ªThis is to understand why even nature finds it difficult to find a solution at larger scales,º he says. ªHovering is something that every bird would like to do. Even an eagle would like to hover at one point.º

scope and tri-axial accelerometer. With both drones the microprocessor takes the raw data from the gyro and accelerometer and directs the aircrafts' controllers — motors and servos — to automatically stabilize them. The autopilot also allows the drones to send and receive data wirelessly, and for the human pilot to provide higher-level commands, on top of the automatic stabilization. But without the stabilization, a human pilot won't be able to fly these vehicles, Benedict says.

The flapping-wing drone was particularly difficult to design and fly because even slight changes to the design affected its response to controls significantly, Benedict says.

The intrinsic instability of the cyclocopter and flapping-wing concepts can actually be an advantage, because designers have developed such a fast-responding control system to handle them, Kroninger says. "So in certain domains, you can quickly move actuators and therefore achieve some level of high control authority."

Cyclocopters, compared to traditional helicopters and quadcopters, are more agile because they can use thrust vectoring — changing the pitch of the rotor blades as the blades rotate through a 360-degree cycle — to directly push the aircraft in any of those 360 degrees, Benedict says. Cyclocopters are also more aerodynamically efficient, with the aircraft producing more thrust per unit of power. Traditional helicopters and quadcopters tilt forward to fly forward, so their advance ratio — the forward speed divided by the fixed speed of the rotor — is typically less than 0.3, while cyclocopters can achieve an advance ratio of 1, so they have the potential to fly faster than the helicopter and quadcopter.

Moving by thrust vectoring instead of tilting also keeps the cyclocopter at a level attitude, which could be an advantage for sensors it might carry, Benedict says. And the entire blade of a cyclorotor produces thrust, compared to just the tips of the rotors on traditional helicopters and quadcopters, which means that cyclocopters can achieve the same thrust at a lower RPM and potentially operate with less noise than traditional helicopters and quadcopters.

Weight control

The biggest disadvantage of the cyclocopter compared to traditional helicopters and quadcopters is that the rotors are heavier, which drives up the weight of the empty cyclocopter, Benedict says. But considering that helicopter technology is so much more advanced than the little-studied cyclocopter concept, he thinks more research will close the gap.

"I still think there's a lot of room for improvement with the cyclocopter to drive down the weight," he explains. "We have an 80- to 90-year history on helicopters — I feel it's kind of unfair to compare the technology, which is so mature. The cyclorotor is still in the early stages."

Benedict and his teammates were able to reduce the weight and increase the strength of the cyclocopter rotors by building the blades out of newer composite materials, dropping an airfoil shape for the blades in favor of a flat insect-wing-like design and anchoring the blades on just one end instead of both. The lower blade weight allowed for a lighter hub and arms in the rotor, which were very heavy in earlier cyclocopter designs to withstand the spinning forces. The team also performed extensive tests to determine the best blade design for maximum thrust and efficiency at the lowest RPM possible, because the faster the cyclorotor spun, the greater the centripetal force and its bending effect on the blades.

"It's not something you can just design without proper scientific understanding," Benedict says. "You need to know how the blade pitching kinematics affect your forces; how does it affect your efficiency." ★

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FUEL-F SPACE TRAVE

FREE

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NASA researchers rattled the propulsion community last year when they reported generating thrust inside a vacuum chamber with electromagnetism instead of propellants. Was the effect real or a product of an unknown source of error? Adam Hadhazy spoke to scientists who aim to find out.

Is it a breakthrough, or baloney? Not long after the turn of the millennium, the EmDrive — catchy shorthand for "electromagnetic drive" — was a mere glimmer at the fringes of space-propulsion research.

The idea was to generate thrust by harnessing a strange effect that seems to happen when electromagnetic energy is circulated in an enclosure. That's where things stood until November, when the concept began commanding mainstream attention after a team of NASA researchers reported in AIAA's Journal of Propulsion and Power that they may have generated an anomalous force with their version of an EmDrive, a force that would fly in the face of conventional physics.

Even the paper's lead author isn't sure whether the mysterious phenomenon is real. It's possible that an error source remains unaccounted for, and that the test article moved a distance imperceptible to the human eye — on the order of 4 to 10 micrometers — for completely mundane reasons. "The body of work we did in the paper helped us eliminate a number of those [error sources] fairly definitively," says aerospace engineer and physicist Harold "Sonny" White, who led the experiment. For other possible sources, "although maybe we put a little bit of a pencil mark through" them, they are "certainly not black-Sharpie-crossed-out."

Nevertheless, White and his colleagues at NASA's Eagleworks advanced propulsion physics laboratory in Houston are confident enough that they are busy planning more tests, despite sometimes skeptical reviews by other technologists who have gone over the paper.

Why has the paper generated so much intense scrutiny? If the effect turns out to be genuine and the technology can be expanded to a meaningful scale, it could portend a revolution in the space industry. Spacecraft would no longer need hundreds of kilograms or even tons of propellant to stay in orbit or explore deep space. The International Space Station, for instance, burns through approximately 4 tons of propellant each year, and more fuel must be delivered to it regularly at a cost of about $20,000 a kilogram.

The test

Specifically, the researchers found that per every kilowatt of microwave energy they pumped into their test article, which has the humble appearance of a tapered, copper bucket, 1.2 millinewtons of force was generated on the test article, roughly the equivalent of a honeybee landing on a flower.

Unlike EmDrive tests abroad that appeared to detect force, the NASA EmDrive experiments took place in a vacuum chamber, this one at the Johnson Space Center, home to Eagleworks. Conducting the test in a vacuum chamber slashed a major possible source of bogus thrust: air warmed up by the experiment's equipment could jar the test article.

How can it be?

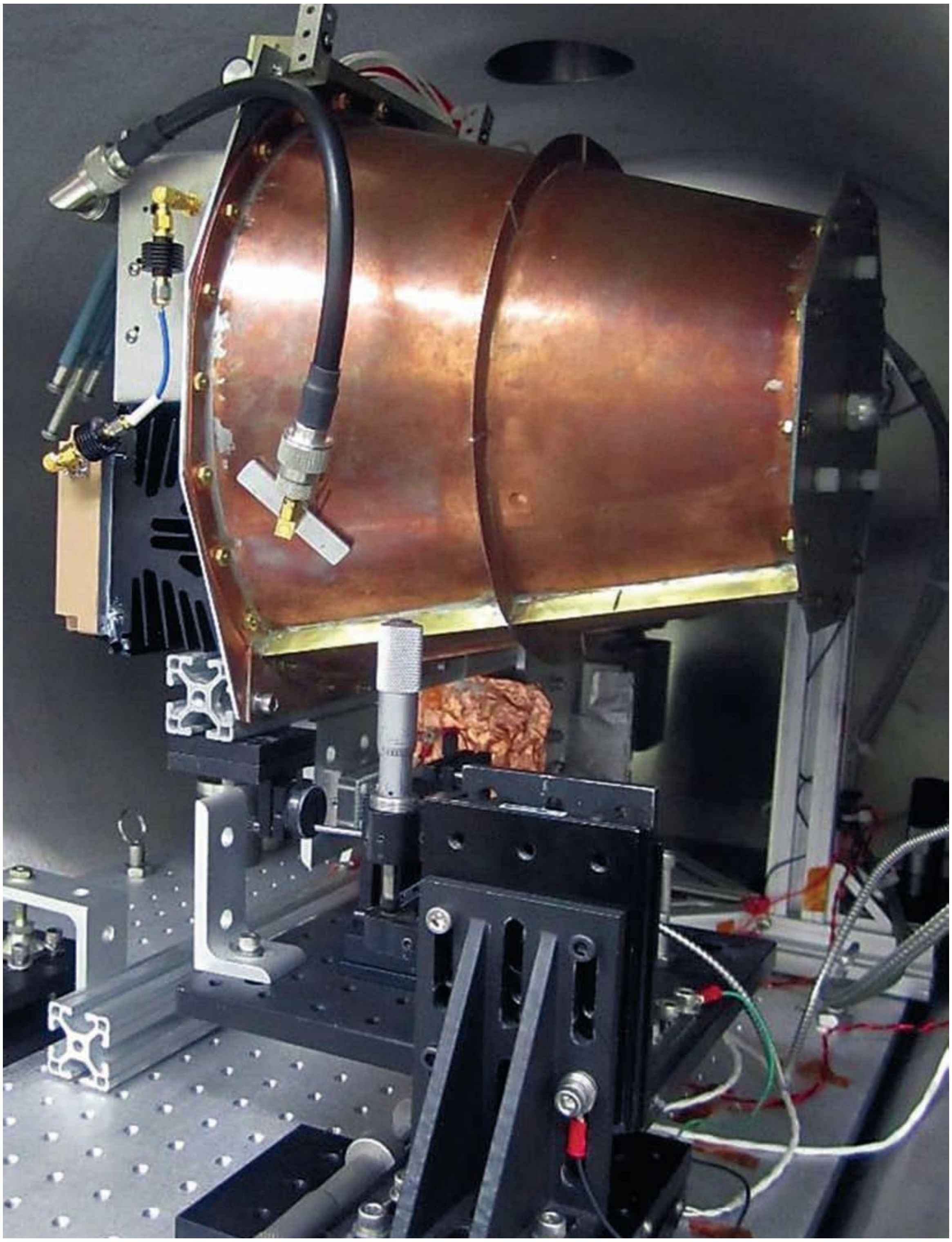
The paper, "Measurement of Impulsive Thrust from a Closed Radio-Frequency Cavity in Vacuum," went through about a year of peer review involving five expert "referees" instead of the more typical two referees. Even so, some physicists remain unconvinced about the EmDrive. "They have a huge hill to climb here, because regardless of how it works, the EmDrive would violate deeply fundamental and well-verified physical phenomena," says Brian Koberlein, a professor of physics at Rochester Institute of Technology in Rochester, New York.

Another skeptic put it even more bluntly. "My perspective is, there's no 'there' there," says Eric Davis, a senior research physicist at the Institute for Advanced Studies at Austin, Texas, as well as a former consultant on NASA's defunct Breakthrough Propulsion Physics Project and who visited White at the Eagleworks lab. "That conical cavity of theirs is a microwave oven," Davis continues, "and we know from physics that microwave ovens can't fly."

Part of the problem might be the breathless headlines touting NASA's verification of an "impossible" or "Star Trek" drive. Seeing this coverage, White is not at all ready to pop a champagne cork. "We're not there yet," he says. Although confident about the EmDrive on one hand, he calls for careful incrementalism on the other. "There are no shortcuts in scientific investigation and in doing empirical observation," White says. "You just have to have patience."

Trendy research

Patience seems to be in short supply, though. Researchers at the China Academy of Space Technology say they have been testing their own version of an electromagnetic drive in space, according to a December article in Science and Technology



NASA

◀ **NASA's EmDrive experimental setup:** Microwaves moving around inside this copper, bucket-shaped test article in Houston appear to have generated thrust toward the article's narrow end, hinting at a potentially propellant-free mode of propulsion.

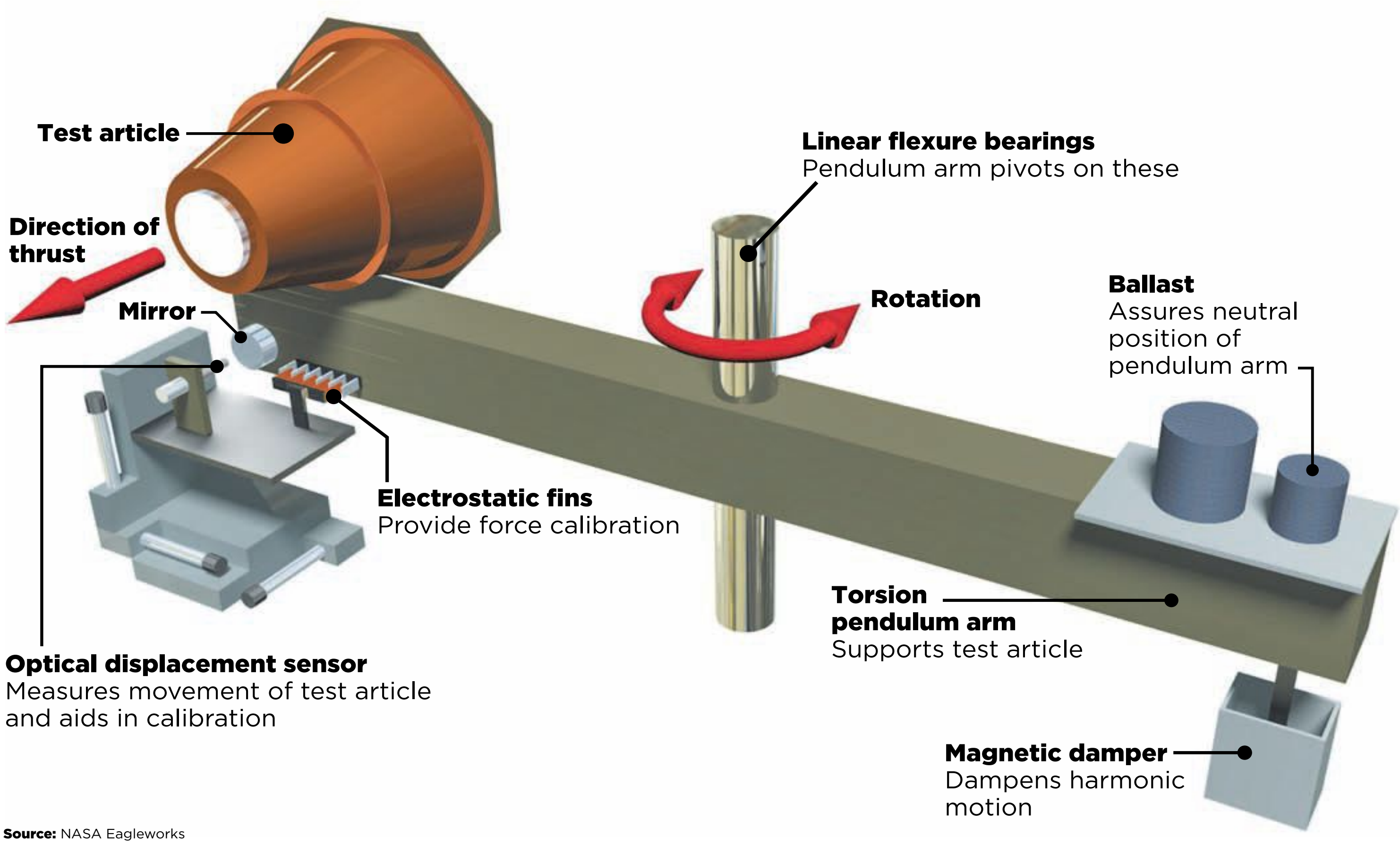
Daily, the newspaper of the Chinese Ministry of Science and Technology. Meanwhile, the Pennsylvania-based company Cannae Inc. has announced plans to launch an EmDrive-like, also-propellantless thruster into space on a cubesat as a technology demonstration.

All in all, it is a meteoric rise for an outré propulsion concept that is not even two decades old. Roger Shawyer, a British aerospace engineer, left Matra Marconi Space, forming his own company in 2001 to develop an electromagnetic drive, technically known as a radio frequency resonant cavity thruster. The concept had occurred to him while evaluating closed-system gyroscopes as a means of thrust for missile control. Despite critics who say his experiments are imprecise and his physical theories questionable, Shawyer has claimed success in experiments over the years. Along the way, his efforts have inspired the aforementioned researchers in China, Germany, and also White and his colleagues, to delve further into the potentially game-changing prospects of the EmDrive.

White and his colleagues recognized that the EmDrive was a long shot, but long shots are the Eagleworks

THE EXPERIMENT

NASA researchers think they may have moved the copper cone below just by circulating microwaves inside it. The results raise the possibility of generating spacecraft thrust without propellants. In a series of test runs, an optical displacement sensor detected subtle movements of a test article attached to a torsion pendulum arm.



Source: NASA Eagleworks

Illustration by John Bretschneider

lab's raison d'etre. Indeed, the EmDrive might be tame compared to other work at the lab, including theoretical and experimental forays into the possibilty of developing a faster-than-light "warp drive," courtesy of isolated bubbles of spacetime.

Not long after the founding of the Eagleworks lab in 2011, White's team decided it was time to take the EmDrive for a spin. What ensued were years of work to set up the experimental apparatus, report preliminary findings in 2014 and conduct a year of peer review for the paper published in November.

The tests at NASA

For his EmDrive, White hewed to Shawyer's design to construct the 23-centimeter-long, copper test article in the geometric shape of a frustum — a cone with its pointy end lopped off. A small antenna inside the test article floods its interior with resonating microwaves.

This test article was mounted to the aluminum arm of a torsion pendulum. This arm was free to rotate horizontally around a linear, vertically oriented flexure bearing, should it experience a force. An optical sensor transmitted a laser to measure the displacement of the movable arm portion of the torsion pendulum from its rest position. White and his team needed to describe this displacement in terms of force, which meant they had to know how far the pendulum would move with a given amount of force. They placed two electrostatic combs opposite each other, one on the pendulum arm and one on some gear near it, so that the fins of the combs interleaved. Before each test run, they charged the combs with particular voltages to induce specific levels of force, and then with the optical sensor measured the separation of the fins. The result was a touchstone they could consult to know how much force was generated on the test article on each run.

Direct current power and data signals traveled from the fixed portion of the torsion pendulum into the movable portion through brass screws into liquid metal contacts made of the trademarked alloy Galinstan, a mixture of gallium, indium and tin that stays liquid at room temperature. These connections eliminated cable interfaces and their confounding forces. To offset the weight of the test article on the torsion pendulum's one end, a ballast weight was placed on its other, while a magnetic dampener converted some oscillatory motion into heat. "That's a way to keep

the system fairly well-damped so it's a nice, clean signal that we can look at," says White. The experiment was done on a "shoestring" budget in line with other low-technology-readiness-level, university or NASA center lab efforts. The cost was on the order of tens or hundreds of thousands of dollars, not millions. "You just try and be as frugal as you possibly can to make forward progress," White says.

The researchers ran the experiment at varying power levels of 40, 60 and 80 watts for periods of 30, 60 and 90 seconds. The optical sensor recorded any displacement of the copper frustrum in both forward and backward orientations on the torsion arm. When all was said and done, on average, a small, but persistent force unattributable to other aspects of the experiment emerged.

White's paper addressed nine possible sources of error for this force, ranging from air currents to vibration to electrostatic interactions of experimental components. Although White is confident that most were ruled out, perhaps the most difficult to counter was the thermal expansion and contraction of the various items mounted on the torsion pendulum arm. That expansion or contraction could tip the center of gravity and yield spurious thrust signals. "That was the thing we worked the hardest to understand and put in a box," White says. "As we move forward, we want to do some more due diligence."

" ... MAYBE WE PUT A LITTLE BIT OF A PENCIL MARK THROUGH" POTENTIAL SOURCES OF ERROR, BUT THEY ARE "CERTAINLY NOT BLACK-SHARPIE-CROSSED-OUT."

— Harold "Sonny" White, NASA Eagleworks

Peer reviews

Rochester's Koberlein applauds White and his team for applying such rigorous peer review. "The whole point of peer review is it puts [research] out there publicly so people can rip it apart," said Koberlein. "That's how we do science and that's the only way we're going to get to the truth."

That said, Koberlein is quick to argue that pre-publication review is, of course, not any guarantee of a study's results, just that its general methodology passed muster with at least one, if not a few, independent scientists. "It's important not to overvalue peer review, because lots of things that have been subjected to peer review have been wrong," says Koberlein.

A recent swing-and-a-miss was BICEP2, short for Background Imaging of Cosmic Extragalactic Polarization, an experiment that gathered relic light from the Big Bang with a telescope near the South Pole. In March 2014, researchers announced collections reported finding evidence for a period of rapid expansion of the universe following the Big Bang. Less than a year later, the team withdrew the claim, and the data was chalked up to mundane, cosmic dust.

At this early stage of digestion of Eagleworks' EmDrive paper, the review from the wider community has ranged from lukewarm to skeptical.

Marc Millis, the former head of NASA's defunct Breakthrough Propulsion Physics Project, and co-authors wrote about the paper on Cenaturi Dreams, the website for his interstellar travel advocacy group, the Tau Zero Foundation. The new study "is an improvement in fidelity on the prior tests and may be indicative of a new propulsive effect," according to the authors, but they went on to observe what they called some shortcomings. Philosophically speaking, the paper's authors lacked impartiality, given their assumptions that the EmDrive somehow or another worked. On the methodological front, Millis and colleagues write that White's team failed to fully characterize the performance of their torsion pendulum; quantitatively assess possible interactions with the vacuum chamber's wall; and exhaustively account for thermal effects. The analysis suffered, Millis and colleagues say, because it could not credibly discriminate which part of the data was due to actual impulse, versus thermal effects. "Questionable subjective techniques are used to infer the 'thrust' from the data," they write.

Davis, who was one of Millis' co-authors, says that before the experiment, White's team "cleaned up" a lot of the potential sources of error , but "they still engaged in a lot of wishful thinking."

Reaching for an explanation

As for the physics behind the EmDrive, White and his team speculate they may be seeing a manifestation of what's known among physicists as a quantum drive or Q thruster. Such a thruster works on

"THE WHOLE POINT OF PEER REVIEW IS IT PUTS [RESEARCH] OUT THERE PUBLICLY SO PEOPLE CAN RIP IT APART."

— Brian Koberlein, Rochester Institute of Technology

the well-accepted principle that empty space is not a vacuum but is frothing with fluctuations in quantum fields, with pairs of virtual particles perpetually forming and mutually annihilating.

Based on an interpretation of quantum mechanics known as pilot wave theory, these vacuum fluctuations can be thought of as a dynamic medium that guides, or pilots, individually observed, "real" particles. And as a medium, the quantum vacuum's constituents can interact and exchange momentum, not unlike a fluid, or a plasma.

As White sees it, the EmDrive can leverage electromagnetic fields to couple with the quantum vacuum and induce a slightly preferential flow in it. "A terrestrial analog to think of is a submarine that sits in the water," White explains. "It takes advantage of the fact it's embedded in its propellant." A submarine uses a propeller to couple with this liquid medium and generate a hydrodynamic pressure gradient. The water moves in one direction and, to conserve momentum, the submarine moves in the other, just like the EmDrive goes one way while a "wake" of virtual particles streams through the quantum vacuum.

According to this explanation, one of the biggest slams of the EmDrive — that it violates conservation

▼Cannae announced that it will launch its proprietary thruster — which it says requires no onboard propellant — into space on a cubesat.

Cannae

of momentum, a bedrock principle of physics — is averted. Yet other physicists are not buying that the Q-thruster argument conserves momentum, famously conveyed as Newton's third law: For every action, there is an equal and opposite reaction. Rochester's Koberlein says extending the third law to the quantum vacuum — in effect, the entire cosmos, anywhere and everywhere — cannot work, because then "what does the cosmos move against?" he asks.

Furthermore, some question that the quantum vacuum operates at all like a plasma, as White contends. The paper also does not present any equations or mathematical predictions for how to relate measured thrust back to a theoretical paradigm, even a wildly conjectured one. "They have nothing to go on theoretically," Koberlein says. "That means they have no convincing way to pull any signal they might have out of the noise [of the experiment]."

But backers posit entirely different theories for how they might work. Shawyer in the U.K. points to electromagnetic waves' momenta being linked to velocity, influenced by the geometry of the tapered EmDrive, thus creating asymmetric forces at its wide and narrow ends. Some speculate on theoretical Unruh radiation, a hypothesized inertia phenomenon caused by virtual particles and in this case felt by microwaves to differing degrees at opposite ends of the EmDrive. An even more outlandish conjecture is that an EmDrive's microwaves might interact with elusive dark matter particles, which although undetected to date, theoretically outnumber particles of regular matter by five to one.

What the future may hold

White seems unfazed by the hubbub surrounding his experiment and is planning his next move. To further tackle the possible bugaboo of EmDrive thermal expansion and contraction, he and his team want to run similar tests on a type of apparatus called a Cavendish balance. In such a setup, the EmDrive could rotate out to much larger angular displacements, such that the thrust force would dominate over any thermal effects. Additional findings also might help to define the underlying physics. "Those are two major brushstrokes that we'll be applying to the canvas," White says. Beyond these next steps, White says it is premature to consider, say, altering the shape of the test article or the frequency of the microwaves to try and squeeze out more oomph. "We really don't have a good sense yet of what particular dials there are for us to be able to grab onto and turn and be able to say you can do this, that or the other," he says. "We're very much in the early phases of trying to understand the engineering and physics and how they interact with one another."

Ames Research Center

▲ **Next, Harold "Sonny" White and NASA** Eagleworks want to test their EmDrive concept on a Cavendish balance. Additional findings might help to define the underlying physics.

Optimistically, a few years ago, White and a colleague ran some figures on what a "Q-ship" outfitted with a fully-fledged EmDrive, could do throughout the Solar System. The researchers assumed a conservative thrust of 0.4 newtons per kilowatt — about 300 times that hinted at in the recent, small-scale experiment, but a tenth of what they ballpark as achievable — supplied by a modest nuclear reactor in space, producing a megawatt or two of electrical power. In this scenario, a one-way trip to Mars could take 75 days — a far cry from the approximately eight months with current rocket technology. More eyebrow-raisingly, trips to the neighborhoods of Jupiter or Saturn would take around 200 and 260 days, respectively, opening up the outer solar system to human exploration.

White realizes this is pie in the sky for now, considering where the EmDrive's development is. "We've got some work to do," he says. "We're still potentially even in the mode of definitively eliminat[ing] all false positives."

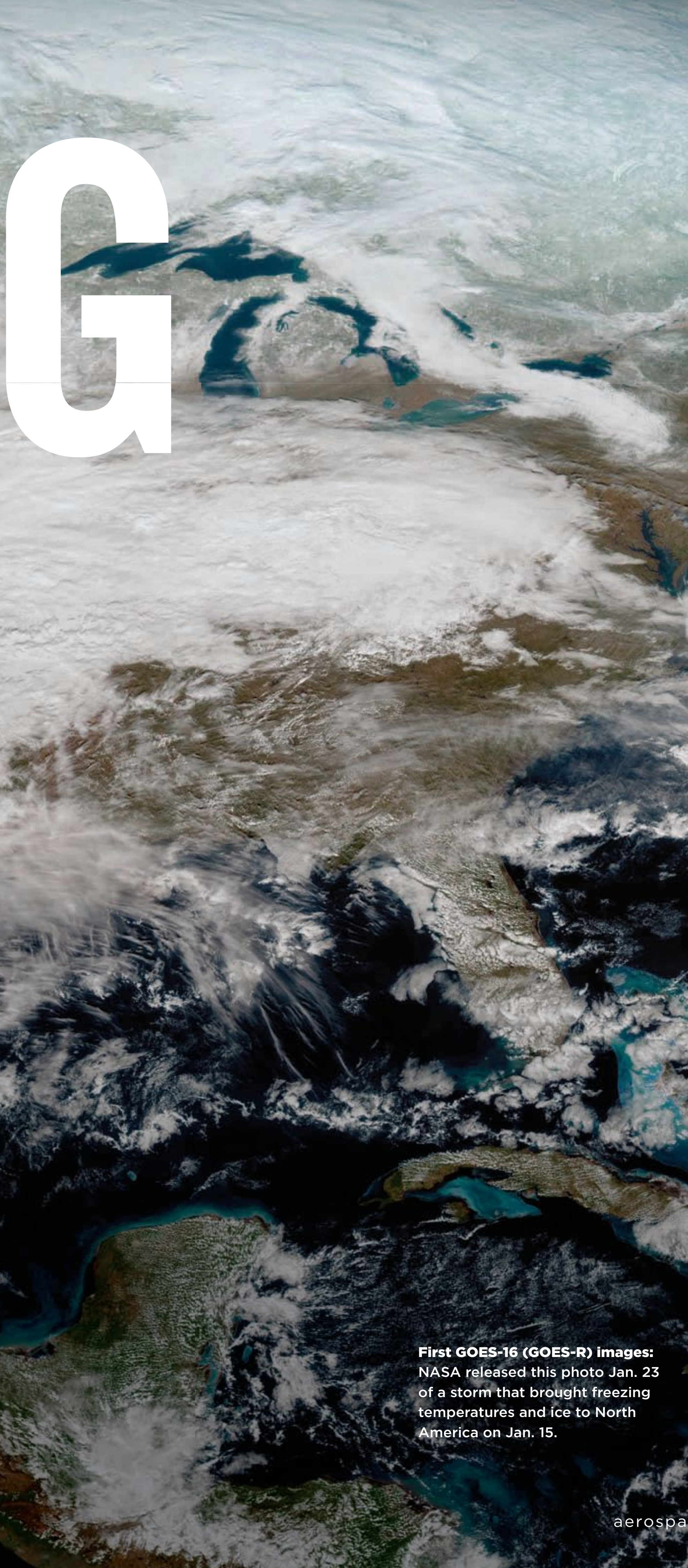
Whether or not the EmDrive will ultimately prove itself in the years ahead, many will be rooting for the Eagleworks team to upend physics as we know it.

"I want them to succeed. I want warp drive, or EmDrive, or whatever. I want to go to the stars," said Koberlein. "But that doesn't make it so." ★

BUILDIN
GOES-R

NOAA's newest geostationary weather satellite and three more like it are expected to dramatically improve severe weather forecasting. Getting the first of these behemoths through development and into orbit was an odyssey of engineering challenges and budgetary hand-wringing. Warren Ferster tells the story.

BY WARREN FERSTER | fersterx@gmail.com



First GOES-16 (GOES-R) images: NASA released this photo Jan. 23 of a storm that brought freezing temperatures and ice to North America on Jan. 15.

NASA/NOAA

NOAA's newest geostationary weather satellite reached orbit in November with a camera that promises to deliver four-times sharper spatial resolution, an event that was once expected to mark the start of a revolution in weather imaging. That distinction ended up going to the Japan Meteorological Agency, which launched a nearly identical camera in 2014 on its Himawari 8 satellite and a second one in 2016 on Himawari 9.

The Japanese satellites stare down on Asia from an altitude of 35,000 kilometers over the equator, much as NOAA's Geostationary Operational Environmental Satellites, or GOES, look down on the continental U.S. and broad expanses of the Pacific and Atlantic oceans. The two GOES spacecraft that do that today (plus a spare in orbit) were joined in November by the most powerful geostationary satellite ever launched for NOAA. It was called GOES-R during construction and then renamed GOES-16 after the launch, as is standard practice. This satellite and its most important payload, the Advanced Baseline Imager, will undergo about a year of testing.

This is the story of how the country that developed this new imaging technology became the second to deploy it. It's an account of hard choices, some good fortune, and lots of difficult engineering challenges as NASA and its contractors struggled to get GOES-R into space for NOAA in time to prevent any risk of an interruption in coverage. The spacecraft is the first of four next-generation satellites that should keep forecasters busy through at least 2036. GOES-S is scheduled for launch in early 2018, followed at some point by T and U.

NOAA is not displeased with how things have turned out. The National Weather Service put a three-year launch delay to good use by receiving data from the Japanese versions of the camera and testing the forecasting models in advance of the GOES-R version, called the Advanced Baseline Imager.

ABI collects reflected light and passes it through a filter and then to a focal plane array made up of individual detector elements. These convert the light into electrical signals. ABI has 16 filters, one per spectral band, each backed by its own array of detector elements.

In addition to the four-times better spatial resolution, ABI will generate pictures five times faster than today's GOES Imagers. The plan is to scan and then focus in quickly on interesting or potentially dangerous weather features. ABI will "scan from the North Pole all the way down

to the South Pole" in five minutes compared to 27 minutes for the existing GOES Imagers, says Greg Mandt, NOAA's GOES-R program manager. "In addition, we'll have the ability to zoom in on a specific storm, like a tornado-spawning complex or a hurricane and look at it every 30 seconds, thereby revolutionizing our ability to forecast weather in near real time."

NOAA and NASA were fortunate that the existing GOES satellites stayed healthy during a series of delays attributable partly to the need to perfect the required technologies. In 2010 and again in 2015, the U.S. Government Accountability Office, the auditing arm of Congress, warned that the age of the existing GOES satellites created a risk that NOAA might end up without a backup in orbital storage. If the satellite in the GOES-East or West slot were to fail, the backup would have to be shifted to take over its duties, leaving NOAA without a second string. That fear did not come to pass. GOES-15, which is in the GOES-East slot, and GOES-13 in the GOES-West slot continue to operate normally, as does the backup, GOES-14, providing plenty of time for testing GOES-16 (formerly GOES-R).

Cost is king

The quantum leap in capability expected from GOES-R did not come cheaply or without painful decisions for those at NOAA who were determined to modernize severe weather forecasting.

Today, ABI is the heart and soul of GOES-R, but the original plan called for a second instrument that was seen by many as equally important, even if it did not deliver photographs. It was called the Hyperspectral Environmental Suite. HES would have vertically profiled the temperature and humidity of the atmosphere in front of storms much faster and with more precision than the existing GOES Sounders. The instrument was called a suite because it also would have measured coastal water properties, including turbidity, temperature and algae concentrations. The forecasting community was ecstatic about the idea of HES. In 2004, NASA, in its role of managing the acquisition for NOAA, awarded HES design study contracts worth $20 million each to three companies: ITT (Now Harris Geospatial Solu-

THE OTHER "AHI"

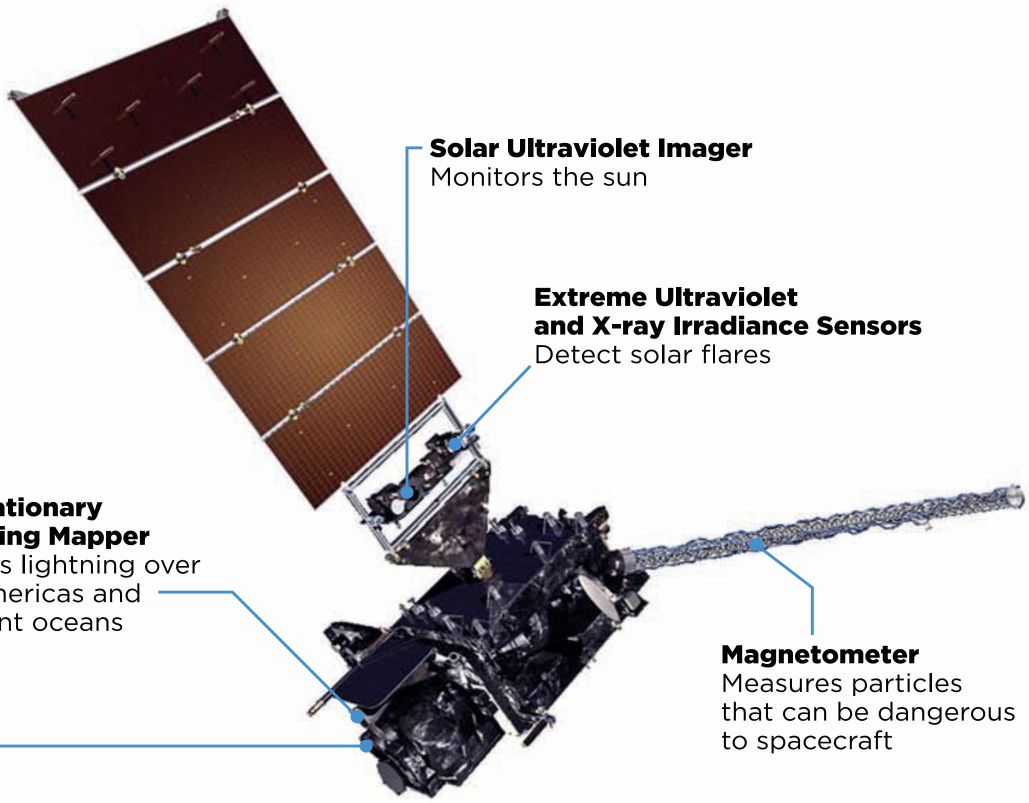
Engineers at what is now Harris Geospatial Solutions in Indiana decided to get creative when it came time to pick a name for the weather imagers they were building for Japan's Himawari 8 and 9 satellites. They called it the Advanced Himawari Imager, or AHI for short, as a play on the Hawaiian term for sushi-grade tuna.

▼ The GOES-R Advanced Baseline Imager arrives at Lockheed Martin's Littleton, Colorado, facility in 2014, for integration with the GOES-R spacecraft bus.

Lockheed Martin

GOES-R instruments

The Advanced Baseline Imager is the primary instrument on GOES-R to send back weather images with four-times better spacial resolution five times faster than previously. Here's a look at the instruments on GOES-16:



Source: NOAA

tions in Indiana), Ball Aerospace of Colorado and BAE Systems of Virginia.

Then came a major budget scrub, one in which NOAA applied a new, more rigorous approach to cost estimating. In 2006, NOAA concluded that if it built every feature of GOES-R in its plan, the program's cost would climb from about $7 billion to roughly $11 billion. NOAA canceled HES that year, citing its technical risks, and reduced the number of satellites to be purchased from four to two, although two have since been added back.

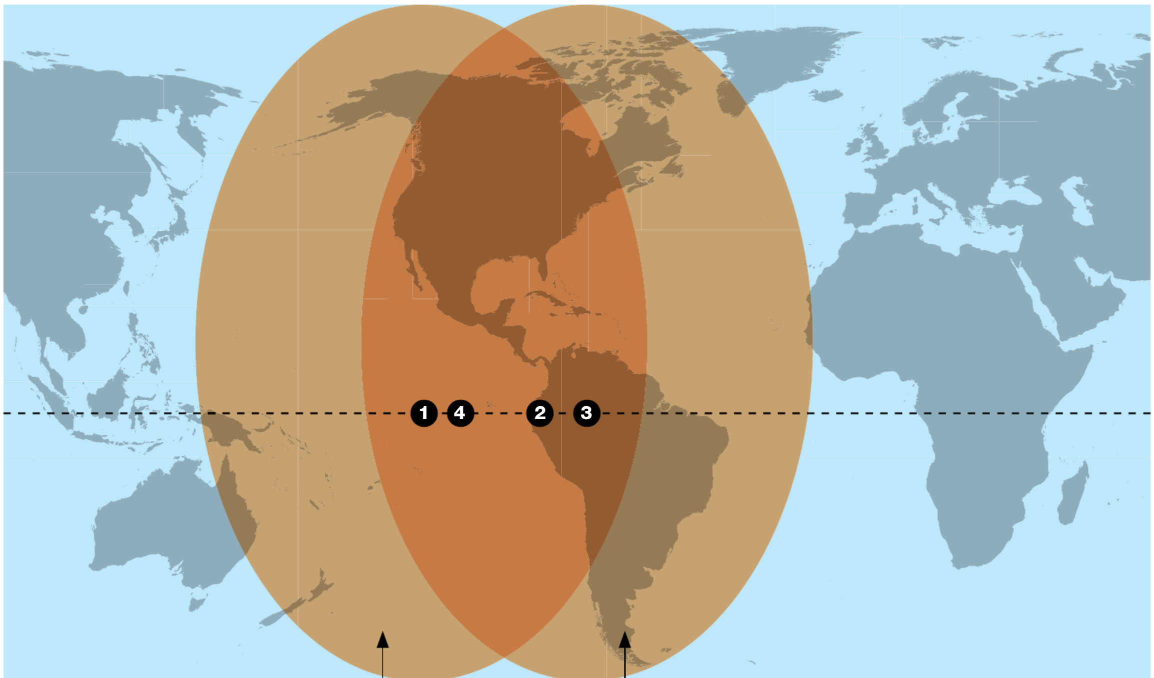
In scrapping HES, NOAA sacrificed what researchers had touted as an improved ability to identify atmospheric changes that might be precursors to severe storm formation. The best NOAA can say now about GOES-R is that it won't lose any ground to today's GOES Sounders. Mandt explains that the infrared channels on ABI, coupled with the faster measurement pace, will effectively replicate the capability of those sounders.

One question about HES was the enormous computing power that would have been required to make sense of its more than 1,000 bands of data. That capability exists today, but in the early 2000s, processing power had not yet reached the point of being able to digest the massive data load that would have been generated, says Paul Griffith, Harris' chief engineer on ABI. He watched HES closely for lessons that might be applied to ABI.

Another factor may have been the new estimating process. In Mandt's view, the higher estimate for GOES-R stemmed not so much from surprising program difficulties, but from this more rigorous cost-estimating process. HES was a casualty of that, he says.

With the GOES-R mission now hinging almost entirely on ABI, all eyes were on that project as engineers broke new ground in instrument design and manufacturing. Along the way, the nameplate of the company would change twice. The work on ABI was begun by ITT Space Systems in Indiana, which in

Approximate Geographic Coverage of the Geostationary Operational Environmental Satellites (GOES)



1. GOES-13
75 degrees west longitude
Launch date: May, 24, 2006

2. GOES-15
135 degrees west longitude
Launch date: March 24, 2010

3. GOES-14 (Orbital storage)
105 degrees west longitude
Launch date: Feb. 13, 2013

4. GOES-16 (Orbital testing; formerly GOES-R)
89.5 degrees west longitude
Launch date: Nov. 19, 2016

Sources: NOAA, Mapart, GAO

GOES-WEST **GOES-EAST**

DISTRIBUTING WEATHER DATA

Data from NOAA's Geostationary Operational Environmental Satellites is too voluminous to be fully processed aboard them. It's sent to the ground for processing and then back up to the satellites, which broadcast it to participating companies or institutions.

2011 was spun off into a new company, Exelis, and renamed Exelis Geospatial Systems. Then, in 2015, Harris Corp. of Florida bought Exelis.

The four-fold increase in spatial resolution was achieved, in part, by adopting photo-voltaic detector elements, which convert light photons differently from the photo-conductive elements used in the GOES Imagers on today's satellites. The goal was more stable performance and a higher signal-to-noise ratio, Harris says.

The ABI detector elements are made of the same materials as on other satellites: silicon for some spectral bands, but the alloy mercury cadmium telluride for most. "It's the same material" as in today's GOES Imagers "but a different architecture," Griffith says.

Despite being laid out on a flat focal plane, each detector element is a complex three-dimensional structure created by a process that involves vapor deposition, etching and ion deposition. The size of the detector elements coupled with their internal structure defines their performance. Computer-driven manufacturing techniques enabled Harris to optimize these features, Griffith says. The detectors had to be produced in large dimensions and in the desired numbers without sacrificing quality. There were hiccups. The initial focal planes didn't have the expected quality and had to be redone.

All told, the ABI arrays provide an exponential increase in the number of detector elements compared to the GOES Imager, with the exact increase varying by spectral band.

Improvements in ground processing were also made, so that the ABI images could be resampled, a technique that applies algorithms to display picture elements in a larger format.

Normally, optical engineers increase resolution by increasing a camera's aperture, so more photons are collected. Harris managed to increase the spatial resolution four-fold with a telescope aperture that's slightly narrower than that of the existing GOES Imagers: 27 centimeters vs. 30 centimeters.

This breakthrough work turned out to be more expensive than planned. In a 2010 report, GAO said that NASA and the ABI contractor underesti-

mated the complexity of two ABI components: the focal plane array and its telescope. As a result, the program's projected cost rose from $375 million to $537 million, the GAO said.

Griffith recalls the problem vividly. Stray photons were entering the telescope, and this was resolved by adding baffles to the structure, he says. Some manufacturing troubles were encountered too, he adds.

Harris' original contract value for the ABI, including development, a prototype and two flight units, was $255 million, Harris says. The company has not released the final value that would reflect two additional flight units, changes in government requirements and some cost overruns.

Another cost factor entirely separate from ABI was development of the GOES-R, Geostationary Lightning Mapper, one of five secondary sensors on the satellite, the others focused on space weather. Its cost rose from $71 million to $157 million, the GAO said.

Griffith concedes that there were moments during ABI's development when it looked like there were no solutions to some of the problems, particularly with the telescope. Ultimately, engineers were able to work everything out.

The results

The ABI contractor ended up delivering the first of the new breed of instruments to NASA about a month before shipping the first Advanced Himawari Imager, or AHI, to Japan for Himawari 8. GOES-R took two years beyond that to reach orbit for a variety of reasons.

One is that it is larger and more complex than Himawari, weighing in at 5,192 kilograms, with fuel, compared to about 3,500 kg for Himawari 8. And while ABI was the most important sensor on GOES-R, managers also had to wait for the other sensors to be delivered and integrated, Griffith says, whereas AHI is the only sensor on each Himawari satellite. Harris is under contract to supply a similar sensor for a South Korean weather satellite slated to launch in 2018.

Not all of the issues had to do with the instruments. As an example, Lockheed Martin Space Systems in Colorado, which built the first GOES-R satellite and is on contract to deliver three more, discovered faulty transistor parts in the satellite. The bad parts, in the Scalable Power Regulator Units, could have prevented GOES-R from charging and discharging its batteries properly, NOAA told lawmakers in late 2015. The parts had to be replaced. This was among the factors that caused the satellite to miss its spot in the busy launch manifest at Cape Canaveral. The launch was bumped from March 2016 to October and finally November.

That's all history now. Once testing of GOES-R is complete, and this first satellite starts operating, the more accurate forecasts could take some getting used to for average Americans. "When I'm at home, and Fairfax County [Virginia] gets a tornado warning, you know what I do? I open my front door to see if I can see it," Mandt says. "We all have heard so many warnings that we don't believe it," he says. With GOES-R, fewer false warnings are expected. "When they hear one they're going to go to safety." ★

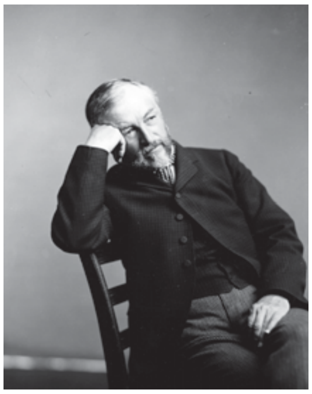
Lockheed Martin

▲ **Engineers and technicians prepare** GOES-S for an acoustics test Dec. 20.

100 YEARS OF LANGLEY

The National Advisory Committee for Aeronautics established the United States' first civilian aeronautics laboratory in Hampton, Virginia, in 1917, a little more than a decade after Orville and Wilbur Wright's historic flight at Kitty Hawk, North Carolina. For 100 years, the Langley Memorial Aeronautical Laboratory, now NASA Langley Research Center, has played a crucial role in the design, testing and development of aircraft and spacecraft, from its development of wind tunnels that transformed aeronautics research to its lunar landing structure that helped put men on the moon to today's efforts to explore Mars. On these pages, we show some of the center's most important achievements. By Debra Werner

1917-1939

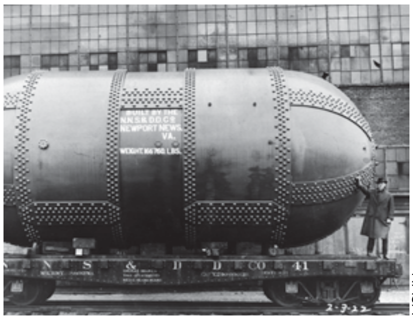


Smithsonian Institution

Samuel P. Langley (1834-1906), astrophysicist and third secretary of the Smithsonian Institution. Langley Memorial Aeronautical Laboratory was named for him.

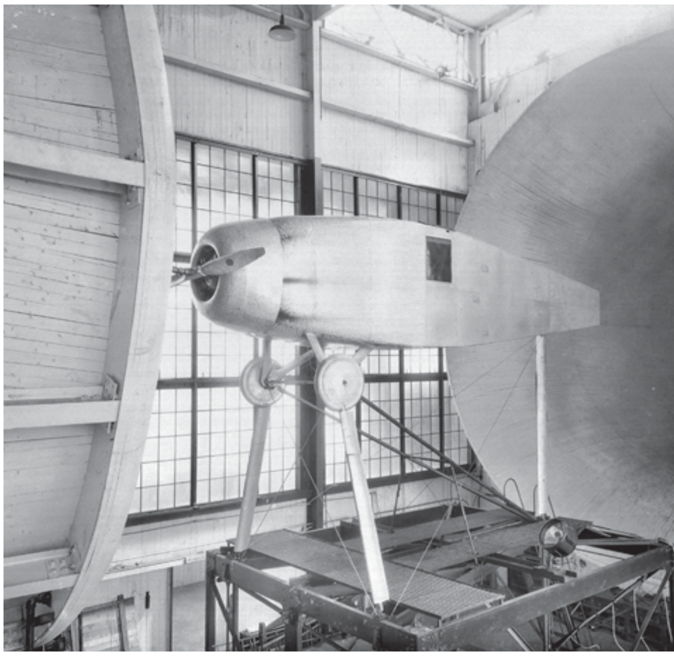
NASA

Langley Laboratory's first wind tunnel, built in 1920.



NASA

Operational at Langley in 1922, the Variable Density Tunnel was the first pressurized wind tunnel in the world.



LANGLEY TIMELINE

1917 The National Advisory Committee for Aeronautics breaks ground on Langley Memorial Aeronautical Laboratory next to Langley Field in Hampton, Virginia, named for Samuel P. Langley, an astronomer, physicist and aviation pioneer.

1920 Langley Laboratory completes its first wind tunnel.

1929 NACA receives the Collier Trophy for Langley Lab's work on cowlings.

1934 The world's largest wind tunnel is built at Langley Field.

1938 A new type of indicator developed at Langley anticipates wing stalls and warns the pilot, NACA announces.

1945 Langley Lab expands to include rocket research.

1947 Air Force pilot Chuck Yeager breaks the sound barrier in the Bell X-1, whose development was made possible by pioneering research in supersonic flight at Langley. .

1958 NACA becomes NASA and NACA Langley Laboratory becomes Langley Research Center.

1959 Seven military pilots report to the Space Task Group at Langley to begin training as America's first astronauts.

1965 NASA Langley opens the Lunar Landing Research Facility.

1969 NASA lands Apollo 11 astronauts on the moon after they underwent training at Langley's Lunar Landing Research Facility.

1970s and 1980s Langley's 8-foot Transonic Pressure Tunnel conducts aerodynamic tests of various space shuttle designs.

1973 NASA Langley sets up an office to look at the environmental impact of supersonic flight.

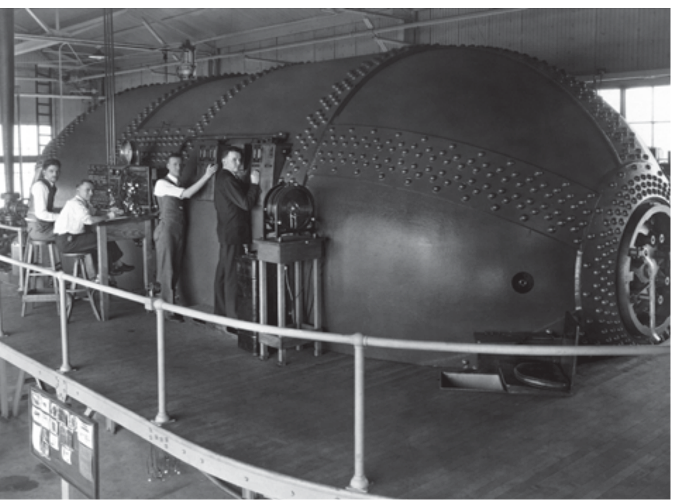
1976 Langley leads the first successful U.S. mission to Mars when the Viking 1 touches down.

1984 In a study of lightning strikes on aircraft, an F-106B fighter takes off from Langley and is struck 72 times.

1992 Langley researchers report developing a fetal heart monitor that can be used at home.

2003 In response to the Columbia shuttle accident investigation, NASA announces Engineering and Safety Center to be opened at Langley.

2016 "Hidden Figures" movie opens, telling the story of female African-American mathematicians who played a key role in NASA's space program.



NASA

◀ **NACA staff conduct** tests on airfoils in the Variable Density Tunnel on March 15, 1929.

NASA

▲ **Metal shop workers** make engine cowlings, which smooth airflow over the engine and reduced drag.

NASA

◀ **A Wright Whirlwind J-5** radial engine mounted in the nose of a representative cabin fuselage with several cowling shapes is tested in the Propellor Research Tunnel in 1928.

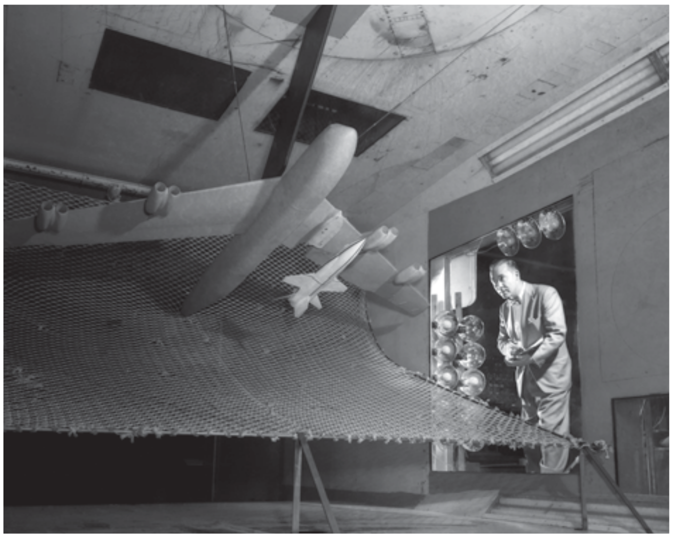
NASA

▲ **President Herbert Hoover presents Collier Trophy to NACA Chairman** Joseph Ames in 1929 for the engine cowling.

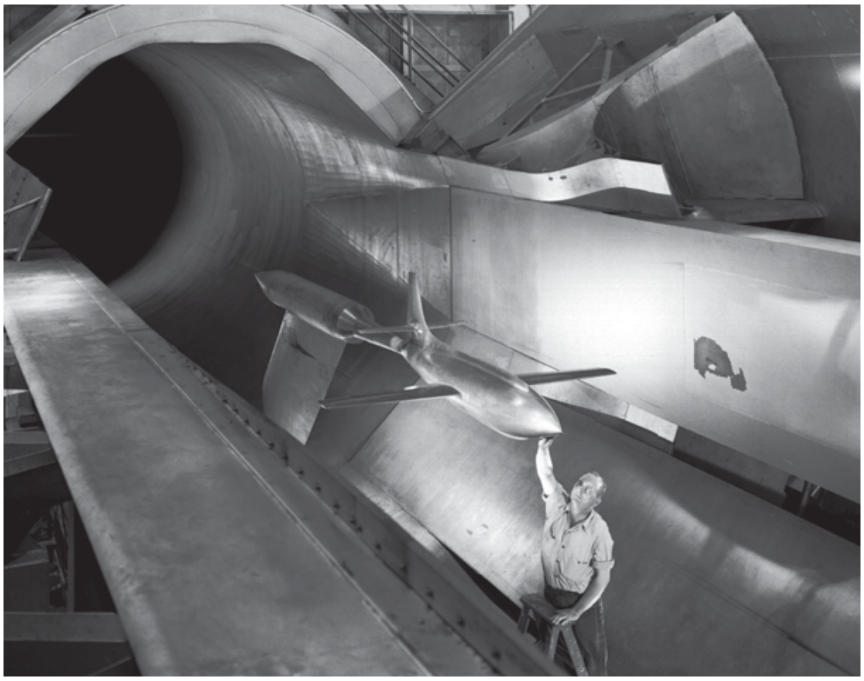
U.S. Air Force

▲ **Capt. Charles E. "Chuck" Yeager** (shown next to the Air Force's Bell-built X-1 supersonic research aircraft) becomes the first man to fly faster than the speed of sound in level flight on Oct. 14, 1947.

NASA



▲ **A one-twentieth scale model** of the X-15, suspended beneath the wing of a B-52 model, helps determine the release characteristics and drop motion of the research airplane.



NASA

▲ **A Langley engineer inspects his installation of a model of the Bell X- 1** supersonic airplane in the new slotted test section of the 16-foot High Speed Tunnel in March 1951.

NASA

X-15 program staff celebrate the first glide flight in June 1959.

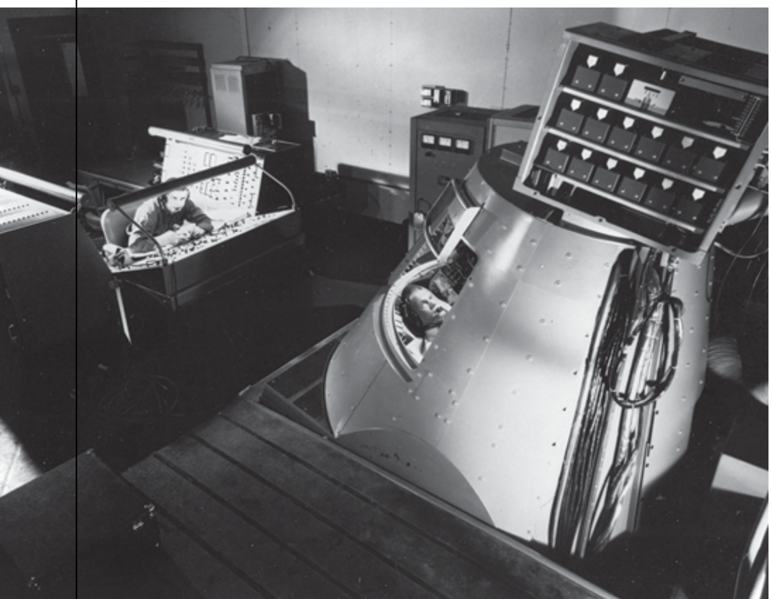
NASA Langley spin tunnel researchers test a Mercury capsule model in 1959.

NASA

NASA

The Mercury space capsule undergoes tests in the Full-Scale Wind Tunnel in January 1959.

1960-1979



NASA

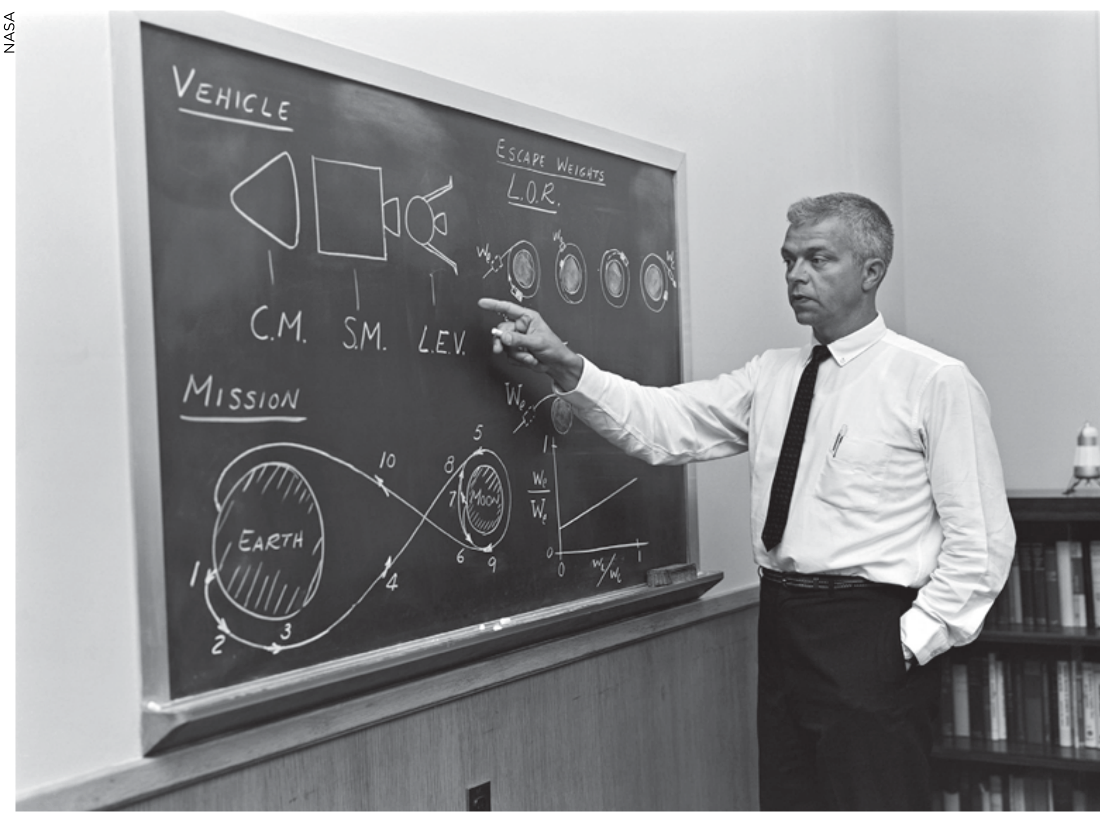
▲ **John Glenn, one of the Mercury 7 astronauts,** runs through a training exercise in 1960, two years before he became the first American to orbit the Earth.

NASA

▲ **After Project Mercury, Langley engineers built a simulator** to help astronauts train to rendezvous and dock Apollo spacecraft.

NASA

▲ **Astronaut Alan Shepard,** in his silver pressure suit with the helmet visor closed, prepares for his Mercury Redstone 3 launch on May 5, 1961, when he became the first American to fly into space.

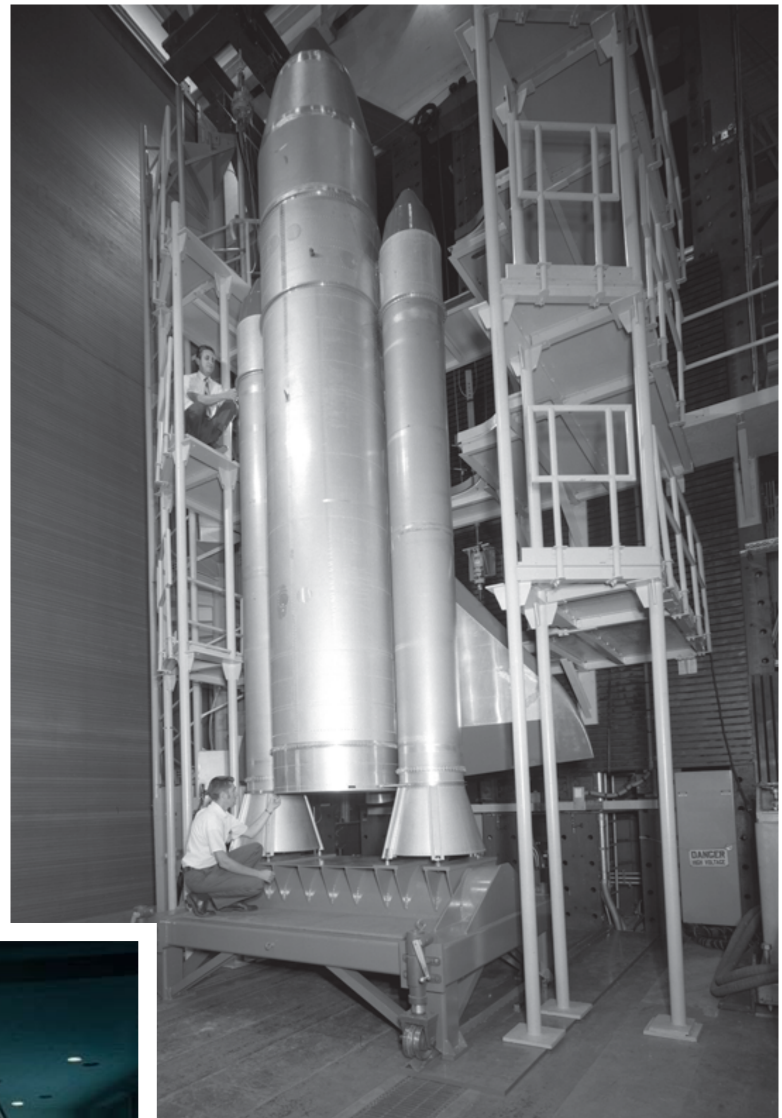


NASA

▲ **Engineer John C. Houbolt describes his space rendezvous concept for lunar landings,** which the Apollo program would use.

NASA

▲ Astronauts used Langley's gantry to practice the last 150 feet of the Apollo 11's descent to the moon's surface. Here it is in 1965.

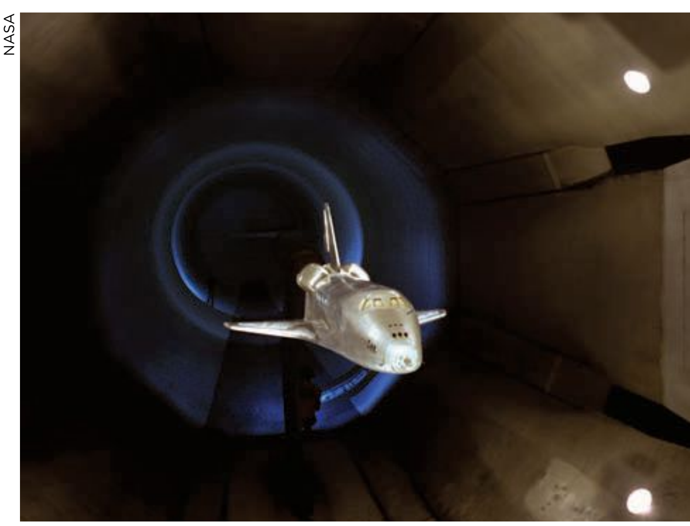


NASA

▲ A one-eighth model of the space shuttle is tested in the Structures Lab in 1973.

NASA

▲ NASA scientists at Langley examine the aeroshell that protected the Viking Lander 1 during its entry into the Martian atmosphere in 1976.



NASA

▲ Engineers test a model of the space shuttle in Langley's 16-foot Transonic Tunnel.

1980±PRESENT

NASA

▲ **The effects of many lightning strikes are visible on an F-106** used for storm research in 1982. The F-106 was another high-speed aircraft developed by Langley engineers and refined through extensive testing in the center's wind tunnels.

NASA

▲ **The Energy Efficient Transport Model undergoes tests** in Langley's 8-foot Transonic Pressure Tunnel in 1992.

NASA

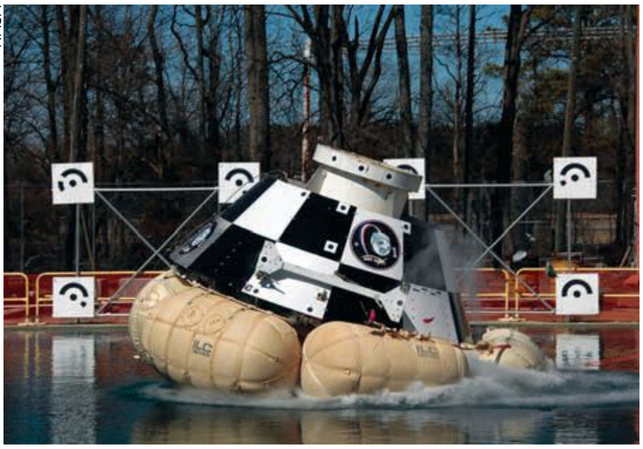
◀ **Langley's Stratospheric** Aerosol and Gas Experiment Satellite leads to the discovery of the existence of a hole in Earth's protective ozone layer.

NASA

◀ **In the 1990s,** Langley researchers adapt aerospace technology to develop a portable fetal heart monitor.

NASA

▲ **The aerodynamics team at Langley in 2014 test a model** of the 70-metric-ton Space Launch System — NASA's heavy-lift launch vehicle that will carry crew, cargo and science missions into deep space.



NASA

▲ **Boeing tests its CST-100 capsule for water landings** at Langley. It is in development under NASA's Commercial Crew Program for transportation to and from the International Space Station.

ILLUMINATING NASA'S "HIDDEN FIGURES"

The movie ªHidden Figuresº centers on the contributions made by African-American women at Langley. In the 1940s with aeronautical research expanding and manpower in short supply due to World War II, Langley recruited women with college degrees to perform mathematical calculations for engineers. The women were referred to as ªcomputersº and assigned to a segregated area known as the West Computer Pool.

Many of the women who started their careers in the West Computer Pool went on to calculate the trajectories of space missions. One of them was Katherine Johnson, who calculated the trajectory of the Mercury capsule that carried Alan Shepard, the first American in space, on his historic 1961 flight. On May 5, 2016, the 55th anniversary of that flight, Johnson attended the dedication of a new building at Langley, the Katherine G. Johnson Computational Research Facility.

1

NASA Langley Research Center

Johnson and her colleagues Dorothy Vaughn and Mary Jackson are prominent characters in the movie, which is based on the book ªHidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Raceº by Margot Lee Shetterly. Shetterly, whose father worked at Langley, started collecting stories of the computers and conducting interviews in 2010.

ªWhen you listen to these women's stories you see that, to them, they were just living everyday lives, doing their jobs and raising families,º says Gail Langevin, Langley's history liaison. ªBut when you step back a little bit and you see that not just men but women and people of all races contributed to our space program, that makes this story exciting.º

More reading:

ªHuman Computersº website: https://crgis.ndc.nasa.gov/historic/Human_Computers

NASA biographies and interviews: https://www.nasa.gov/modernfigures

2

NASA/JPL-CalTech

3

NASA

1 **NASA research mathematician Katherine Johnson** works at her desk at NASA Langley Research Center with a globe, or "Celestial Training Device," in 1962.

2 **Computers weren't always made of motherboards** and CPUs. In this 1959 photo, a human "computer" works with an early machine called the IBM 704.

3 **Mary Jackson grew up in Hampton, Virginia,** earned her bachelor of science degrees in mathematics and physical science, and taught in Maryland before joining NASA.

Why modern planes crash

It sounds counterintuitive, but technical advances are not always a pilot's friend. Robert J. Stewart, a former aeronautical engineer and pilot examiner, warns that certain kinds of air crashes will persist if more attention is not given to old-fashioned hand-flying skills.

The FAA's newly updated requirements for pilot certification — the Airman Certification Standards — represent a renewed emphasis on aeronautical decision-making while acknowledging advancements in avionics technology. All FAA-certified pilots, including those trained by the U.S. military, must obtain the proper FAA certificate, using the revised standards, whether flying a Cessna or an airliner.

The ACS published last June provide a useful integrated method for students and instructors by eliminating irrelevancy in training and testing for private and instrument pilots flying small planes. I was pleased to serve on the FAA's Airman Certification System working group that advised the agency on the standards. Next, the ACS process for commercial, flight instructor and airline transport pilots will be addressed.

Boeing

▲ **Despite modern sophisticated cockpits,** Robert J. Stewart writes, instructors need to emphasize basic flying skills when training pilots.

As worthwhile as these updates are, we need to do even more to address the frustratingly persistent problem of air crashes due to pilot error in the general aviation and commercial transport arenas. This persistence has to do with shortcomings in pilot training and inadequately designed human-machine interfaces of the complex modern aircraft.

Let's first look at how we got here.

Absent the torrent of data in today's cockpits, the airmail pilot of the 1920s somehow managed to fly without succumbing to in-flight upset issues, in which the altitude or airspeed is outside the normal bounds. He was able to survive in those days of avionics-free "contact" flying through outstanding airmanship and skill.

So, why are many of today's pilots more prone to error than those airmail pilots? I propose that it is in large part because of the introduction of the technically advanced aircraft that coincided with the concept that one should train in the same aircraft that you will ultimately be flying.

Many major flight schools, in order to produce pilots for airlines, started using the technically advanced aircraft training concept. We trained pilots to become managers of multifunction displays and autopilots. This coincided with the poor "human factors" design of the original glass cockpits in terms of automation and human-machine interface. In the early 2000s, the original glass primary flight display created a training problem. The glide slope needle was moved from the horizontal situation indicator to the attitude indicator. This reduced the glide slope needle to a small unpronounced tab that was also difficult to monitor from the instructor's seat on the right. This particular human-machine-interface shortcoming persists today, and is but one example of questionable human factors design.

The analog flight instruments were replaced with digitized displays, reminiscent of an earlier version of tape displays tried on Beechcraft Bonanzas and subsequently dropped. A lot that's good can be said for the analog or "steam gauge" displays where a glance at the clock position of the needle provides you with needed information without interpreting and internalizing a numeral. Although some of the manufacturers did recognize the shortcomings of the digitization of the displays and provided glass steam gauge displays, the new glass cockpits quickly evolved into an overload of information, much of which you really didn't need, and required a pilot training system that concentrated on avionics management when we needed to be teaching basic flying skills. That partly explains where we are today.

Also, the airlines wisely employed scenario testing in the ongoing flight training that they require pilots to undertake through their careers. But this was offset by the introduction of the technically advanced aircraft to initial flight training. Instructors switched their emphasis from acquiring basic flying skills to an overemphasis on reacting to various scenarios. This shift involved de-emphasizing the fundamental stand-alone disciplines of aerodynamics, weather, aircraft systems and in-flight maneuvering.

If you doubt that a revised approach should be adopted for training, consider that in response to the February 2009 crash of Colgan Air Flight 3407 in Buffalo, New York, and the crash a few months later of Air France Flight 447 off Brazil, pilots were instructed to reduce the angle of attack for stall recovery. This resulted in the advent of upset prevention and recovery training by both general aviation and the airlines. This training is welcome, but the need for it was a troubling revelation that many pilots have lost or never acquired the skill to handle stalls.

Old school
The airmail pilot of the 1920s survived the days of avionics-free “contact” flying through outstanding airmanship and skill.

The Air France crew did not recognize that they were in an aerodynamic stall and rode the airplane from 38,000 feet to the ocean surface in a stalled condition. Similarly, the Colgan crew may have confused a wing stall with a tailplane icing stall and applied the wrong control inputs for stall recovery.

A further threat to piloting skills in the small aircraft segment is the introduction of the ballistic recovery system, a parachute designed to bring the entire aircraft softly to the ground in an emergency. This technology originated with the structurally unsound ultralights, is currently in use and is reportedly being eyed for larger, privately flown planes. The recovery system turned out to be an effective marketing concept to attract new pilots, but it trades training in basic piloting skills and judgment and risk management, for hitting people on the ground with a falling airplane.

With proper training and an adequate human-machine interface, a pilot does not need a recovery system. Dedicated maneuver training in accuracy landings and ADM will prepare the pilot for all emergency landings short of the remote possibility of structural failure. Adoption of a ballistic recovery system violates the unwritten pilot’s creed of “don’t hurt anyone on the ground, don’t hurt your passengers, don’t hurt yourself and lastly don’t hurt your airplane,” in that order. The ballistic recovery system turns this on its head and does nothing for developing ADM and airmanship skills. I predict that the ballistic recovery system will go the way of the parachute flare for emergency off-airport night landings, because future aircraft designs will be aimed at a more experienced customer base. If there is any doubt about flying being a fine art form, one need only watch film of the late aerobatic pilot Al Williams flying his Grumman Gulfhawk, the late Bob Hoover flying his Shrike Commander or Chesley “Sully” Sullenberger’s “Miracle on the Hudson.”

Focus on basic airmanship skills

So, that is where we are and how we got there. More can be done. The solution to modern airplane crashes lies in improving the human-machine interface, ensuring that pilots acquire basic airmanship and ADM skills, and the proper training in the use of technology that the airmail pilot never had.

> **Flying schools and instructors are not doing aspiring pilots justice by putting them in sophisticated cockpits and teaching them how to push buttons and manage computers.**

Flying schools and instructors are not doing aspiring pilots justice by putting them in sophisticated cockpits and teaching them how to push buttons and manage computers. Student pilots need basic flying skills to learn how to fly a plane before learning how to turn it over to a computer.

As a volunteer member of the Airman Certification System working group, I am pleased that it provides a detailed cross-referenced flying handbook coded to correlate with the knowledge and practical portions of the certification exam. Now we have to make sure new pilots are trained to fly the airplane, not the computer.

It is noteworthy that Boeing has announced it soon will offer the first touch screens in commercial airliners in response to customer demand, suggesting that Boeing thinks it has solved the problem of trying to use the screens in air turbulence. Can we learn from the past to improve our future? I think so.

As we obtain more technology and automation, instead of asking the question “is this doable?” and then proceeding to do it, we should be asking the question, “should we be doing it?” in terms of both technological aircraft design and how we train our pilots. ★

Robert J. Stewart
is a member of the FAA’s Airman Certification System working group. He was an FAA-certified flight instructor and an aeronautical engineer for Beech Aircraft and the Grumman Aircraft Engineering Corp. during development of the Apollo Lunar Module. Stewart flew his Beechcraft Bonanza for 49 years.

FEATURE MICHAEL PECK | michael.peck1@gmail.com

DEFENDIN

In the year 2135, a 500-meter-wide asteroid named Bennu will approach the Earth so closely that it will pass inside the moon's orbit.

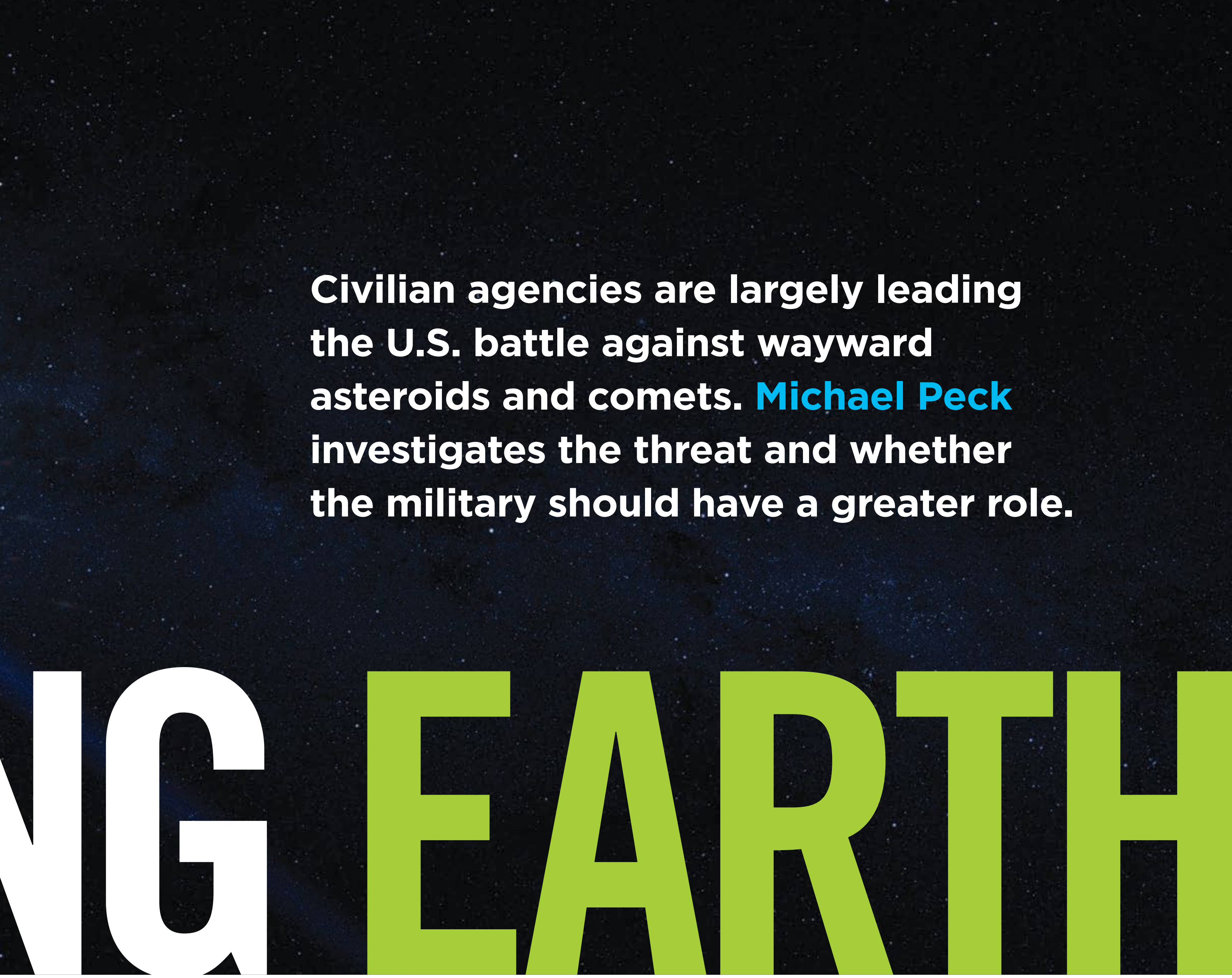
That's a close call in interplanetary terms, though for the inhabitants of Earth, a near-miss is good enough. Nonetheless, what worries astronomers is what comes next. Passing so close to Earth and its gravity will alter Bennu's orbit, which means the next time it comes, it might not miss our planet.

Concerns over such a catastrophe have increased in recent years as the government and the scientific community contemplate the need for planetary defense against asteroids and comets known as near-Earth objects, or NEOs. A December 2016 "National Near-Earth Object Preparedness Strategy," released under the auspices of the White House's Office of Science and Technology Policy, listed seven steps for a U.S. planetary defense strategy, including developing better methods for detecting and deflecting NEOs.

The next step is an action plan that will specify how these goals will be implemented.

As it stands in 2017, the job of stopping Bennu — or any other asteroid headed to Earth — rests with civilian space agencies. Yet mostly absent from the planetary defense discussion is the U.S. military. The Air Force does operate the Space Surveillance Telescope, a DARPA-designed device in Australia that tracks asteroids as well as orbital debris. Otherwise, Earth's planetary defense efforts are strictly civilian, in the hands of organizations such as NASA, the European Space Agency and an assortment of scientists who work on protection in their spare time.

Yet planetary defense seems to have as much in common with military operations as it does with traditional space exploration. For starters, consider what planetary defense entails. Detection of a distant object, preferably with maximum early warning time. Identification of that object,



NG EARTH

Civilian agencies are largely leading the U.S. battle against wayward asteroids and comets. Michael Peck investigates the threat and whether the military should have a greater role.

Goddard Space Flight Center Conceptual Image Lab

and its trajectory and impact, followed by computation of how and where to intercept the asteroid to prevent it from striking Earth. Does this sound familiar? Instead of a space rock, it could have been a Soviet intercontinental ballistic missile streaking in over the North Pole during the Cold War, one of Saddam Hussein's Scuds, or a North Korean ballistic missile today.

The most authoritative guide to planetary defense seems to be a 2010 National Academy of Sciences study, which recommended a suite of defensive measures to stop asteroids: gravity tractors, kinetic impactors and nuclear devices (and, if all else fails, civil defense to minimize damage when the big rock hits). The choice of method depends on the size of the asteroid, and how close it is to Earth when detected. "No single approach to mitigation is appropriate and adequate for completely preventing the effects of the full range of potential impactors," the study concludes.

This sounds much like a terrestrial layered air and missile defense system, which uses successive barriers to stop an attacker. A prime example is a U.S. Navy aircraft carrier battlegroup. The carrier's jet fighters intercept attackers hundreds of miles from the battlegroup. Surviving attackers must then penetrate medium-range shipboard surface-to-air missiles at a range of about a hundred miles, with the remaining intruders forced to pass through a final barrage of short-range anti-aircraft missiles and guns.

The analogy is somewhat crude to be sure. Asteroids don't take evasive action or jam radar signals, and people on Earth are trying to deflect objects, not blow them out of the skies. Nonetheless, gravity tractors can be likened to the long-range layer of an air defense system. The idea is to orbit a small spacecraft around an object. The craft would activate its engines, and through its tiny but persistent gravitational pull, tug the asteroid off its collision course with Earth. NASA

▲ **This artist's rendering** illustrates a collision of space objects like the event that may have created rubble that coalesced to form the asteroid Bennu, which will approach Earth in 2135.

will test the concept with the Asteroid Redirect Mission, or ARM, initially scheduled for December 2020 but postponed until December 2021. The mission calls for the solar-electric powered ARM spacecraft to land on a large asteroid, use its robotic arm to pick up a large boulder, and tow it into orbit around the moon. ARM will test two capabilities, according to Lindley Johnson, NASA's planetary defense officer. First, towing a boulder into lunar orbit will demonstrate the utility of using solar-electric craft to haul objects around the inner solar system and as preparation for a human Mars expedition.

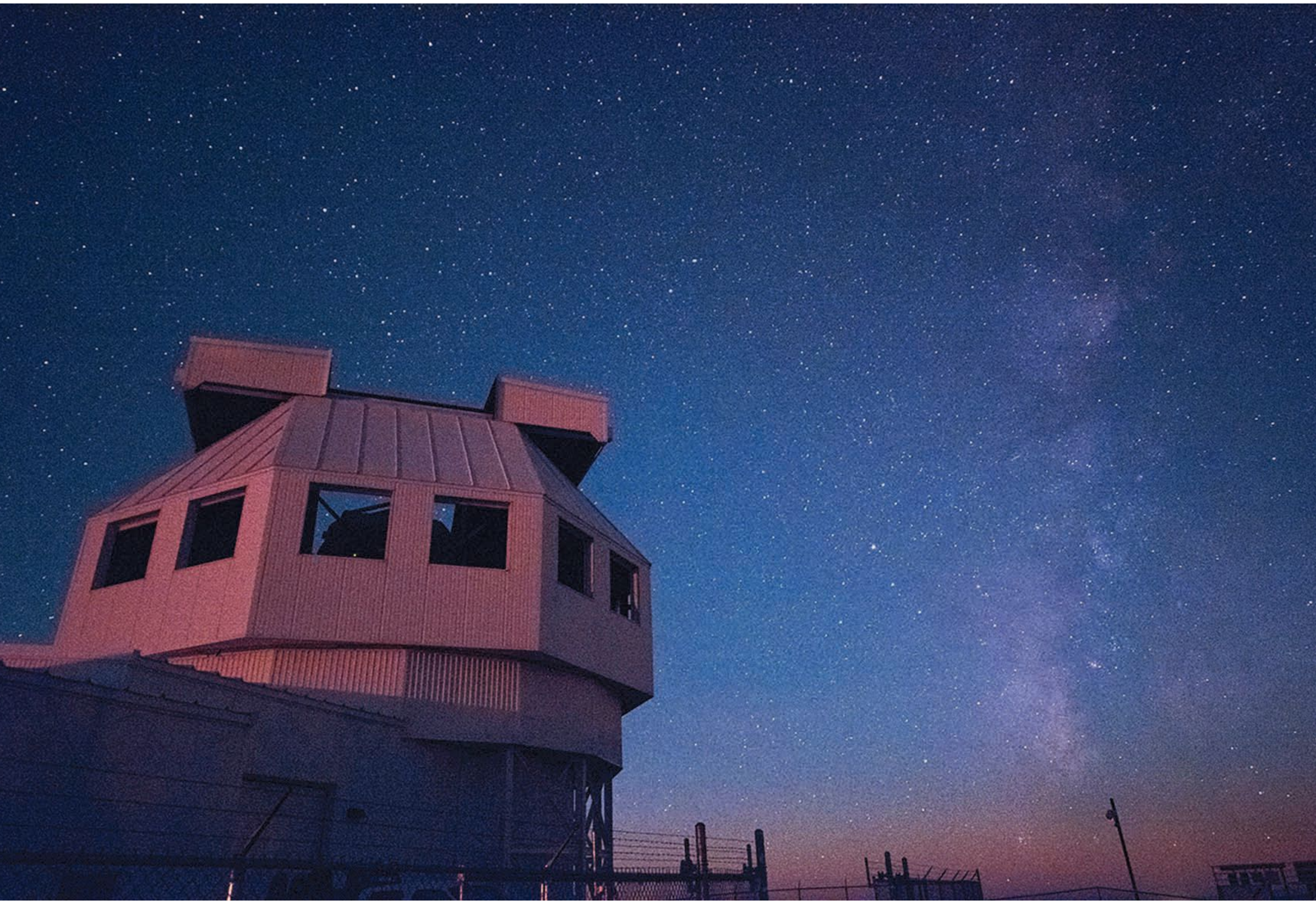
Johnson doesn't see this method as powerful enough to pluck asteroids from a collision course with Earth. "This capability might eventually be grown to handle natural objects as large as 10 meters in size for, say, asteroid mining operations, but this is still so small an object that Earth's atmosphere would protect the surface from significant effects anyway."

However, what ARM will also test is whether a large enough mass can alter the orbit of an asteroid so it doesn't hit Earth. After the spacecraft picks up the boulder, the duo will maintain station with the asteroid for weeks or months before heading to the moon, enabling NASA to determine whether the asteroid suffered a very slight, but measureable, deflection.

Gravity tractors are the least violent of the planetary defense options, what Johnson describes as a "rather creative and benign" solution. So benign in fact that a gravity tractor requires the asteroid to be detected several decades before impact to give the spacecraft enough time to work, according to the National Academy of Sciences study. In addition, a gravity tractor can't tug anything larger than a medium-sized asteroid.

But what about objects detected a decade or two out, in Earth's medium-range defense zone? The weapons of choice are kinetic impactors. Like a pool cue striking a billiard ball, a spacecraft will strike an asteroid with such force as to deflect the asteroid from its impact trajectory. "You only have to impart a very small force, a small change in velocity, years in advance to make a direct impact a miss," Johnson says.

▼ The Space Surveillance Telescope in Australia, operated by the U.S. Air Force, is one of the few military efforts designed to track asteroids and orbital debris.



DARPA

The technique was indirectly tested against asteroids in 2005, when NASA's Deep Impact mission slammed a 370-kilogram impactor into comet Tempel 1, creating a 150-meter-wide crater that allowed scientists to examine the internal composition of a comet. The real demonstration was supposed to come with the Asteroid Impact and Deflection Assessment, or AIDA, mission, a collaboration among NASA, the European Space Agency, the German Aerospace Center, Observatoire de la Côte d´Azur, and The Johns Hopkins University Applied Physics Laboratory. AIDA was a dual-spacecraft mission aimed at 65803 Didymos, a binary with an 800-meter asteroid orbited by a 150-meter companion. As NASA's Double Asteroid Redirection Test, DART, craft slammed into the companion, the European Space Agency's Asteroid Impact Mission craft would observe whether the rock changed its orbit around the primary. However, the European Space Agency opted last December not to fund its spacecraft, though U.S. scientists say they could continue the mission just with DART.

Kinetic impactors also happen to be the weapon the Pentagon will use to attempt to shoot down ballistic missiles. The ground-based Exoatmospheric Kill Vehicle and Standard-Missile 3 destroy missiles by slamming into them in space. For that matter, science-fiction writer Jerry Pournelle in the 1950s proposed "Rods from God," orbital satellites launching kinetic projectiles that would destroy targets on the ground.

While Johnson agrees that "the principles are largely the same with kinetic technologies explored by the Missile Defense Agency," he also sees major differences between ballistic missile defense and planetary defense. The intercept velocities for an asteroid are at least three times faster than a missile, and often much faster, while the space rocks also have far more mass. Anti-missile weapons also have too short a range to stop an asteroid in time, and "their effect would be somewhat analogous to a bug hitting the windshield of a semi-tractor trailer," Johnson says. That said, he also believes that some missile defense technology, especially software, may be useful for planetary defense, including the upcoming DART test of a kinetic impactor on an asteroid.

Finally, we come to the ultimate nightmare scenario: An asteroid detected just a few years before impact, which leaves too little time for gravity tractors or kinetic impactors. While astronomers are confident they have discovered most of the devastating kilometer-sized NEOs, the recent White House report noted that only 28 percent of objects 140 meters or larger — that is, bigger than the 1908 Tunguska impact that devastated 2,000 square kilometers in Siberia — have been spotted.

Leonid Kulik

▲ **A meteor exploded above the Tunguska River** in Siberia on June 30, 1908. A Russian expedition to the site almost 20 years later shot this photograph.

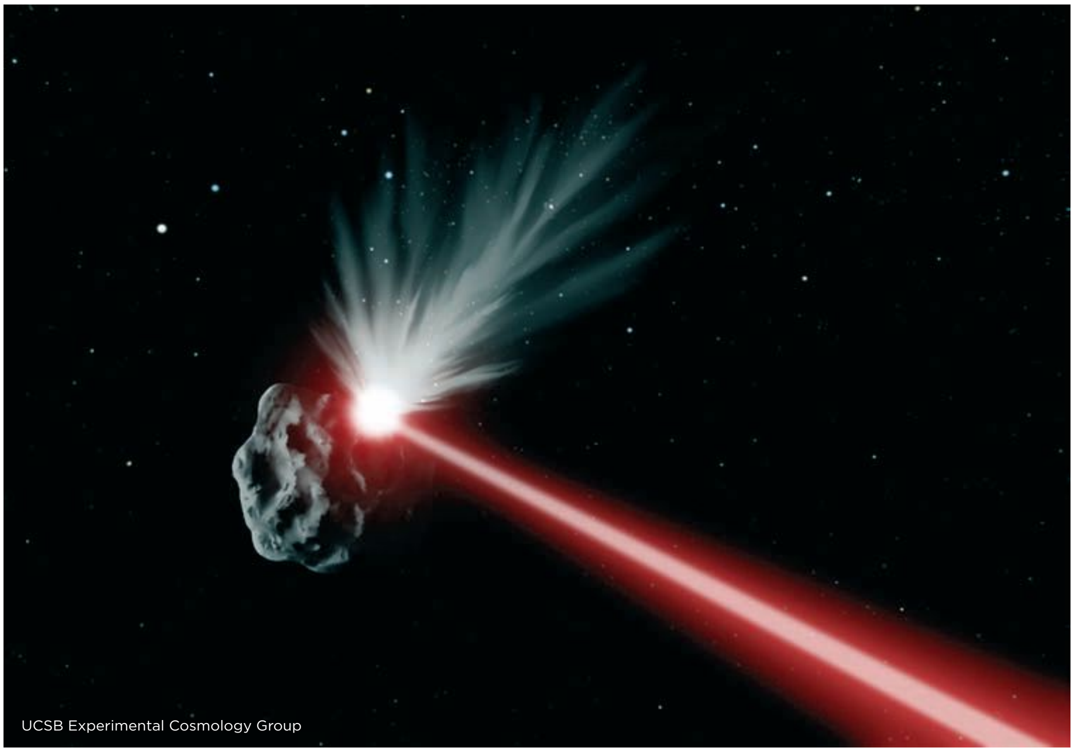
Or, perhaps the object is simply too big to be deflected by a projectile or towed into a new orbit. Then comes the ultimate option, one that has not been unleashed in anger since 1945: a nuclear device. Detonated at a specified distance from an asteroid, it would emit a barrage of X-rays that would vaporize the asteroid's surface. The resulting plume of material would be like a rocket engine, changing the asteroid's trajectory.

"We call it the technique of last resort," Johnson says, "if we don't have a lot of warning or a lot of time, and we need to give something a pretty good shove."

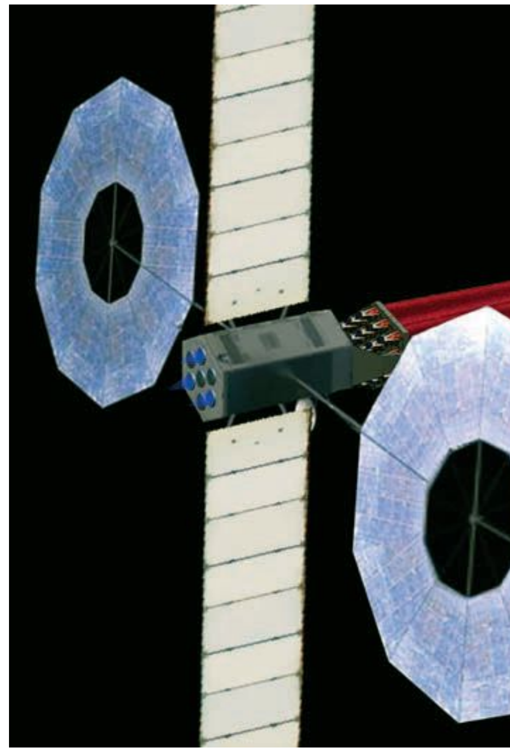
As far as the technique's effectiveness, Paul Miller, a physicist who heads planetary defense research at Lawrence Livermore National Laboratory, says that nuclear devices have some advantages. They can be used against objects that have not been detected until relatively close to Earth. "If you get to within, say, three years of warning, and an asteroid that's a couple hundred meters, then you're starting to have some difficulty with kinetic impactors."

They also offer more control when it comes to applying just enough force to deflect an asteroid, but not so much that the asteroid fragments into a cloud of mini-asteroids that pummel the Earth. "The nice thing about stand-off nuclear explosions as a technique is that their effect can be dialed down if you just move them farther away from the asteroid."

However, one problem with anti-asteroid nuclear weapons is political fallout. Space law expert Joanne Gabrynowicz notes that nuclear asteroid-busters could run afoul of the 1963 Limited Test Ban Treaty, which prohibits nuclear testing and explosions in outer space, and the 1967 Outer Space Treaty, which bars nuclear weapons from being placed in Earth orbit, on the moon, or in outer space.



UCSB Experimental Cosmology Group



▲ **Directed Energy System for Targeting** of Asteroids and Exploration, or DE-STAR, would stay in Earth orbit and use a laser to protect Earth from asteroids and other near-Earth objects, as depicted in this artist's representation.

Regardless of whether such a treaty would actually stop a nation from nuking an asteroid headed toward it, it makes testing more complicated.

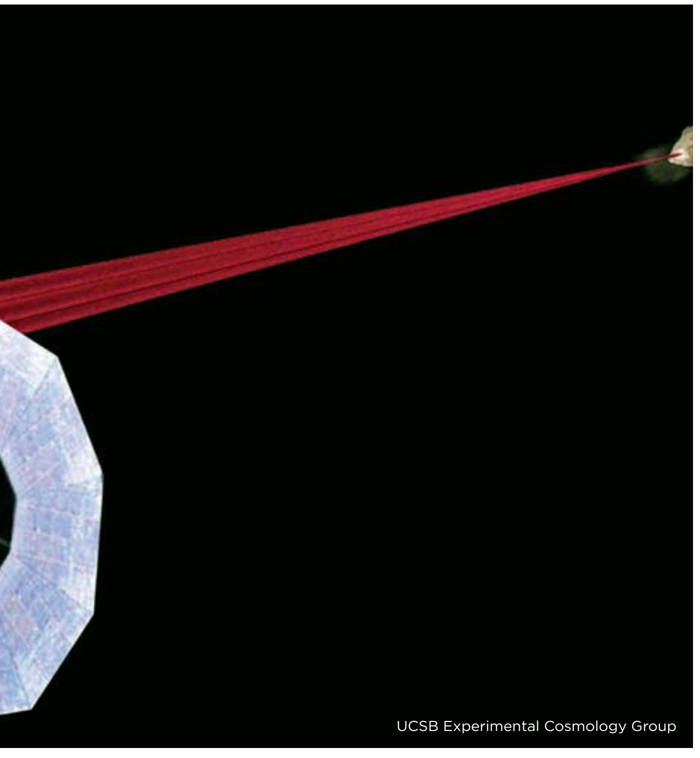
And though Lawrence Livermore designs nuclear weapons, Miller emphasizes that no one there is pushing for the nuclear option. "We are not saying we need a test or want a test in space."

There are still other ideas for planetary defense that seem to have more in common with military defense. One proposal calls for lasers that would heat the surface of asteroids to around 3,000 degrees Kelvin, creating a jet of vaporized rock that would push the asteroid off its course with a force that its creator claims is as powerful as a space shuttle engine. The concept sounds broadly similar to the missile defense lasers being developed by several nations, including the U.S. and Israel. DE-STAR, or Directed Energy System for Targeting of Asteroids and Exploration — the brainchild of University of California Santa Barbara physicist Phil Lubin — would come in two flavors: what Lubin calls a "stand-off" (a familiar military word) version consisting of a kilometers-wide Lego-like orbital array of 1-kilowatt laser amplifiers that could target an asteroid out to 1 astronomical unit. The "stand-on" version would orbit a laser-armed satellite around an asteroid, and melt a spot on its surface with a 50-kilowatt laser, the same type of laser that the U.S. Army uses as a truck-mounted tactical weapon against rockets and mortar shells. Lubin estimates that the stand-on DE-STAR satellite would need to fire its laser for three years to deflect a 100-meter asteroid. The most bizarre idea may be a variation on the biblical injunction to turn swords into plowshares. In this case, it's a Russian missile maker that proposed earlier this year to turn ICBMs into asteroid-busters. In February 2016, Russia's Tass news agency reported that the Makeyev Rocket Design Bureau, which made ICBMs for the Soviet Union and now makes them for Russia, has proposed using converted ICBMs to destroy asteroids between 20 and 50 meters in size. Makeyev argues that because ICBMs are designed for immediate launch, they are ideal for destroying asteroids that have not been detected until within a few hours of striking Earth. The company would like to test the concept on the asteroid Apophis as it nears Earth in 2036.

However, one expert at an American rocket manufacturer questioned the logic of the approach. ICBMs are battery-powered and designed for short flights, not deep-space missions, the expert says. "You would be much better off with a space launch vehicle with a deep space bus on it." And because ICBMs are designed to carry nuclear warheads, which are relatively small objects, they can carry only a few tons of payload. Besides, if an asteroid is detected so close to Earth that a few days of fueling time makes a difference, it's too late to deflect it.

Yet even if planetary defense does have military characteristics, does that mean the military should handle planetary defense? NASA and civilian experts do not seem pleased at the thought of military intervention, perhaps not surprising given a history of occasionally troubled relations between the military and the civilian space sectors.

"Our Department of Defense is focused on manmade threats to our national security, and frankly already has too much on their plate with the resources they have been given for the space arena,"



UCSB Experimental Cosmology Group

The DE-STAR "stand-on" version would travel to the asteroid or comet to deflect it from its trajectory toward Earth.

Space is a target-rich environment. Paul Chodas, who manages NASA's Center for Near Earth Object Studies, puts the latest estimate for near-Earth objects at four asteroids greater than 10 kilometers in diameter, and 940 greater than 1 kilometer. That covers the really big ones, but scientists also estimate there are about 25,000 asteroids greater than 140 meters, and 250,000 can be dismissed as small fry. The Tunguska asteroid strike, an airburst that devastated 2,000 square kilometers of Siberian forest in 1908, is estimated to have been about 40 meters in diameter. In addition, 1,705 NEOs have been classified as potentially hazardous asteroids, meaning they are greater than 140 meters and will come within 0.05 astronomical unit, or about 7.5 million kilometers, of Earth, a hair's breadth in cosmic terms.

says Johnson, a former Air Force officer who served two tours with Air Force Space Command before coming to NASA. "It is understandable why they are not enthusiastic about adding this exceptionally rare naturally occurring hazard to their missions, particularly if there is a better agency to handle it — that being NASA."

Johnson and others point out that to the military deep space is geosynchronous orbit, or 35,000 kilometers from Earth. There is no reason for the Pentagon to have a capability to operate out by Mars.

"It's not that the military doesn't have capabilities," says arms control expert Jeffrey Lewis, who has also written about planetary defense. "It's that we already have a pretty healthy civilian capability."

Lewis also notes that while the military delivers nuclear weapons, it's actually the Department of Energy, a civilian agency, that builds them. Thus a nuclear device — and experts are at pains to call it a device and not a warhead — could be launched by NASA without Department of Defense involvement. "Fundamentally, I think this is an astronomy problem," adds Lewis. "I think the best thing to do is to fund telescopes to look for these objects."

But something the Pentagon does have is a $583 billion annual budget, which dwarfs NASA's $19.3 billion budget, not to mention the $50 million allocation for the space agency's Planetary Defense Coordination Office. Strangely, while Johnson says planetary defense could use more resources to develop detection and mitigation technologies, he also adds that "this does not warrant even a $500 million per year effort."

NASA's Planetary Defense Coordination Office has only about eight people working part time. "At Lawrence Livermore, we are putting the equivalent of less than two full-time people on this project," Miller says. "It's a couple of full-time post-docs and a number of other staff — 10 or 12 people — who contribute their expertise to really pull the whole project together."

Johnson says his office supports the efforts of about 200 people in the United States at NASA centers and other scientific sites, plus some assorted astronomers. But planetary defense right now is an overwhelmingly part-time effort. This baffles Lubin, who believes the human race is "rolling dice" with the fate of Planet Earth.

"The people working on this are trying to save the planet in their spare time," says Lubin.

He sees the problem as a lack of leadership. "It's nobody's problem. It's not NASA's problem. It's not the military's problem."

"Waiting for a threat to occur, and planning for it then, is like waiting for an adversary to launch a missile at you, and then say, 'It's time to develop a missile defense system.'" ★

AIAA Bulletin

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We are frequently asked how to submit articles about section events, member awards, and other special interest items in the AIAA Bulletin. Please contact the staff liaison listed above with Section, Committee, Honors and Awards, Event, or Education information. They will review and forward the information to the AIAA Bulletin Editor.

Notes About the Calendar

For more information on meetings listed below, visit our website at www.aiaa.org/events or call 800.639.AIAA or 703.264.7500 (outside U.S.).

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2017			
5±9 Feb[2]	27th AAS/AIAA Space Flight Mechanics Meeting	San Antonio, TX (Contact: www.space-flight.org/docs/2017_winter/2017_winter.html)	7 Oct 16
4±11 Mar[2]	IEEE Aerospace Conference	Big Sky, MT (Contact: www.aeroconf.org)	
6±9 Mar[2]	21st AIAA International Space Planes and Hypersonic Systems and Technology Conference (Hypersonics 2017)	Xiamen, China	22 Sep 16
17±18 Mar	Region VI Student Conference (San Jose State University Student Branch)	San Jose, CA (https://www.aiaastudentconference.org/)	
20±21 Mar	Region II Student Conference (Mississippi State University Student Branch)	Starkville, MS (https://www.aiaastudentconference.org/)	
25±26 Mar	Region III Student Conference (University of Michigan at Ann Arbor Student Branch)	Ann Arbor, MI (https://www.aiaastudentconference.org/)	
29 Mar	AIAA Congressional Visits Day (CVD)	Washington, DC (http://www.aiaa.org/CVD/)	
5±7 Apr	Region VII-Europe-Pegasus/AIAA Student Conference (Masters Division Only)	Berlin, Germany (https://www.aiaastudentconference.org/)	
7±8 Apr	Region I Student Conference (University of Virginia Student Branch)	Charlottesville, VA (https://www.aiaastudentconference.org/)	
7±8 Apr	Region V Student Conference (Metropolitan State University of Denver Student Branch)	Denver, CO (https://www.aiaastudentconference.org/)	
18±20 Apr[2]	17th Integrated Communications and Surveillance (ICNS) Conference	Herndon, VA (Contact: Denise Ponchak, 216.433.3465, denise.s.ponchak@nasa.gov, http://i-cns.org)	
25±27 Apr	AIAA DEFENSE Forum (AIAA Defense and Security Forum) Featuring: ±AIAA Missile Sciences Conference ±AIAA National Forum on Weapon System Effectivenss ±AIAA Strategic and Tactical Missile Systems Conference	Laurel, MD	4 Oct 16
25±27 Apr[2]	EuroGNC 2017, 4th CEAS Specialist Conference on Guidance, Navigation, and Control	Warsaw, Poland (Contact: robert.glebocki@mel.pw.edu.pl; http://www.ceas-gnc.eu/)	
29±30 Apr	Region IV Student Conference (University of Houston Student Branch)	Houston, TX (https://www.aiaastudentconference.org/)	
2 May	2017 Fellows Dinner	Crystal City, VA	
3 May	Aerospace Spotlight Awards Gala	Washington, DC	
8±11 May[2]	AUVSI/AIAA Workshop on Civilian Applications of Unmanned Aircraft Systems	Dallas, TX (www.xponential.org/auvsi2016/public/enter.aspx)	
15±19 May[2]	2017 IAA Planetary Defense Conference	Tokyo, Japan (Contact: http://pdc.iaaweb.org)	
25±29 May[2]	International Space Development Conference	St. Louis, MO (Contact: ISDC.nss.org/2017)	
29±31 May[2]	24th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (Contact: Ms. M. V. Grishina, icins@eprib.ru, www.elektropribor.spb.ru)	
3±4 Jun	3rd AIAA CFD High Lift Prediction Workshop	Denver, CO	
3±4 Jun	1st AIAA Geometry and Mesh Generation Workshop	Denver, CO	

†Meetings cosponsored by AIAA. Cosponsorship forms can be found at https://www.aiaa.org/Co-SponsorshipOpportunities/.

AIAA Continuing Education offerings

AIAA Symposiums and Workshops

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
5±9 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition) Featuring: ± 24th AIAA Aerodynamic Decelerator Systems Technology Conference ± 33rd AIAA Aerodynamic Measurement Technology and Ground Testing Conference ± 35th AIAA Applied Aerodynamics Conference ± AIAA Atmospheric Flight Mechanics Conference ± 9th AIAA Atmospheric and Space Environments Conference ± 17th AIAA Aviation Technology, Integration, and Operations Conference ± AIAA Flight Testing Conference ± 47th AIAA Fluid Dynamics Conference ± 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference ± AIAA Modeling and Simulation Technologies Conference ± 48th Plasmadynamics and Lasers Conference ± AIAA Balloon Systems Conference ± 23rd AIAA Lighter-Than-Air Systems Technology Conference ± 23rd AIAA/CEAS Aeroacoustics Conference ± 8th AIAA Theoretical Fluid Mechanics Conference ± AIAA Complex Aerospace Systems Exchange ± 23rd AIAA Computational Fluid Dynamics Conference ± 47th Thermophysics Conference	Denver, CO	27 Oct 16
5±6 Jun	Cybersecurity Symposium at AIAA AVIATION Forum	Denver, CO	
6±7 Jun	DEMAND for UNMANNED at AIAA AVIATION Forum	Denver, CO	
6±9 Jun²	8th International Conference on Recent Advances in Space Technologies (RAST 2017)	Istanbul, Turkey (Contact: www.rast.org.tr)	
7±9 Jun	Transformative Electric Aircraft Workshop & Expo at AIAA AVIATION Forum	Denver, CO	
19±21 Jun²	9th International Workshop on Satellite Constellations and Formation Flying	Boulder, CO (Contact: http://ccar.colorado.edu/iwscff2017)	
10±12 Jul	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition) Featuring: ± 53rd AIAA/SAE/ASEE Joint Propulsion Conference ± 15th International Energy Conversion Engineering Conference	Atlanta, GA	4 Jan 17
20±24 Aug²	2017 AAS/AIAA Astrodynamics Specialist Conference	Stevenson, WA	24 Apr 17
22±24 Aug²	International Conference on Aerospace Science and Engineering (ICASE)	Islamabad, Pakistan (Contact: http://www.ist.edu.pk/icase)	
12±14 Sep	AIAA SPACE Forum (AIAA Space and Astronautics Forum and Exposition)	Orlando, FL	23 Feb 17
13±16 Sep²	21st Workshop of the Aeroacoustics Specialists Committee of the Council of European Aerospace Societies (CEAS)	Dublin, Ireland	
25±29 Sep²	68th International Astronautical Congress	Adelaide, Australia	28 Feb 17
2018			
8±12 Jan	AIAA SciTech Forum (AIAA Science and Technology Forum and Exposition) Featuring: ± 26th AIAA/AHS Adaptive Structures Conference ± 56th AIAA Aerospace Sciences Meeting ± AIAA Atmospheric Flight Mechanics Conference ± AIAA Information Systems Ð Infotech@Aerospace Conference ± AIAA Guidance, Navigation, and Control Conference ± AIAA Modeling and Simulation Technologies Conference ± 20th AIAA Non-Deterministic Approaches Conference ± 28th AAS/AIAA Space Flight Mechanics Meeting ± 59th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference ± 5th AIAA Spacecraft Structures Conference ± 36th Wind Energy Symposium	Orlando, FL	

Class of 2017 AIAA Associate Fellows Honored

The Class of 2017 AIAA Associate Fellows were recognized at the AIAA Associate Fellows Recognition Ceremony and Dinner on 9 January at the Gaylord Texan, Grapevine, TX, in conjunction with AIAA SciTech Forum.

CLASS OF 2017 AIAA ASSOCIATE FELLOWS

Region I Class of 2017 Associate Fellows

Region II Class of 2017 Associate Fellows

Region III Class of 2017 Associate Fellows

Region IV Class of 2017 Associate Fellows

Region V Class of 2017 Associate Fellows

Region VI Class of 2017 Associate Fellows

Region VII Class of 2017 Associate Fellows

AIAA Announces its Class of 2017 Fellows and Honorary Fellows

AIAA has selected its Class of 2017 AIAA Fellows and Honorary Fellows. The induction ceremony for the new Fellows and Honorary Fellows will take place at the AIAA Aerospace Spotlight Awards Gala on 3 May at the Ronald Reagan Building and International Trade Center in Washington, D.C.

"The work and leadership of AIAA Fellows and Honorary Fellows consistently ensures that today's aerospace dreams become tomorrow's realities," said AIAA President Jim Maser. "They are individuals who have each shown a tireless dedication to shaping the future of aerospace. AIAA congratulates the members of the Class of 2017 Fellows and Honorary Fellows on their selection."

Honorary Fellow is the highest distinction conferred by AIAA, and recognizes preeminent individuals who have had long and highly contributory careers in aerospace and who embody the highest possible standards in aeronautics and astronautics. The 2017 Honorary Fellows are:

- Natalie W. Crawford, RAND Corporation
- Alan H. Epstein, Pratt & Whitney
- Bradford W. Parkinson, Stanford University

AIAA confers the distinction of Fellow upon individuals in recognition of their notable and valuable contributions to the arts, sciences or technology of aeronautics and astronautics. The 2017 Fellows are:

- Naval Agarwal, The Boeing Company
- Karl Bilimoria, NASA Ames Research Center
- Thomas Butash, Innovative Aerospace Information Systems
- Nancy Jan Davis, Jacobs Technology, Inc.
- Ari Glezer, Georgia Institute of Technology
- Steven Griffin, The Boeing Company
- Naira Hovakimyan, University of Illinois
- Eric Loth, University of Virginia
- Frank Lu, University of Texas at Arlington
- Roger McNamara, Lockheed Martin Corporation
- Daniel Miller, Lockheed Martin Corporation
- Gary Polansky, Sandia National Laboratories
- Richard Powell, Analytical Mechanics Associates, Inc.
- Mark Psiaki, Virginia Polytechnic Institute and State University
- Lesa Roe, NASA Headquarters
- Heidi Shyu, U.S. Army (Ret.)/Heidi Shyu, Inc.
- George Sowers, United Launch Alliance
- Ben Thacker, Southwest Research Institute
- John Valasek, Texas A&M University
- Julie Van Kleeck, Aerojet Rocketdyne
- Todd Zarfos, The Boeing Company

For more information on AIAA's Honors Program, or the AIAA Honorary Fellows or Fellows Program, please contact Patricia A. Carr at 703.264.7523 or triciac@aiaa.org.

10th Annual AIAA Pacific Northwest Section Technical Symposium: Innovations in Aerospace and Beyond

On 19 November 2016, the AIAA Pacific Northwest (PNW) Section hosted its 10th annual PNW AIAA Technical Symposium—with the theme "Innovations in Aerospace and Beyond"—at the Future of Flight Aviation Center in Everett, WA. Since 2007, the symposium has become one of the highlights of the year for local members, especially for those who are unable to participate in a national AIAA event.

This year's symposium was kicked off by John Thornquist, director of the Office of Aerospace, Washington State Department of Commerce, who highlighted the importance of the aerospace industry in the region. Mr. Thornquist was followed by Dr. Mark D. Moore, senior advisor for On-Demand Mobility and principal investigator for the Scalable Convergent Electric Propulsion Technology Operations Research X-Plane (SCEPTOR) at NASA Langley Research Center. Dr. Moore captivated the audience with his keynote on emerging opportunities for electric propulsion for intra-urban on-demand air travel.

The symposium continued in three parallel sessions, two of which comprised technical presentations from Dr. Roger Myers, former executive director of Advanced In-Space Programs at Aerojet Rocketdyne for many years and a space technology and business consultant with 29 years of hands-on leadership experience, discussing novel propulsion technologies enabling low-cost space missions; Dr. Behçet Açıkmeşe, associate professor in the William E. Boeing Department of Aeronautics and Astronautics, Engineering Department, University of Washington, explaining optimization for guidance and control of autonomous aerospace vehicles; Dr. Roger A. Parker, CTO of AirMarkets Corporation, describing revenue management for the air charter industry; Jeanne Yu, director of Technology Integration for Boeing Commercial Airplanes, on innovation toward sustainable aviation; and William Van Valkenberg, vice president of SmartSky Networks, LLC, describing SmartSky Networks' High Bandwidth Wi-Fi in the Sky.

The third parallel track—organized by AIAA PNW's Young Professionals council members—was the Rising Leaders forum, which is always very popular with students and early-career professionals. This track started with a keynote from Kristina Hayek, U.S. Instructional Design and Development Manager for Hexcel Corporation, on "7 Tips to Take Your Career Sky High" and was followed by a lively discussion with the participants on items such as how to keep motivated when the going gets tough or what you can do to prepare yourself for the career you want. A returning session under the Rising Leaders track is the speed mentoring, during which the symposium participants get a chance to talk one-on-one with the speakers and other industry leaders.

Lunch included an inspiring presentation by Vera Mulyani, CEO, lead architect and founder of "Mars City Design" and president of Mars City Foundation, who challenged the audience to think about what life on Mars would look like, what things or experiences we might miss from our home on Earth, and what an architect should think of when designing a city on Mars. Ms. Mulyani's presentation was followed by Dr. Nicholas Patrick, Human

Figure 2. Dr. Mark Moore (NASA Langley Research Center) presenting the plenary opening keynote presentation on Electric Propulsion and Emerging Aviation Market Opportunities.

Figure 2. Dr. Keith Goodfellow (Aerojet Rocketdyne) delivers a presentation on advances in Electric Propulsion in Space Programs in a parallel session.

Integration Architect, Blue Origin, at the keynote luncheon presentation on the current status of Blue Origin's New Shepard spaceflight program, as well outlook onto their New Glenn's orbital launch system.

The luncheon presentations were followed by two presentations on parallel tracks. A panel discussion, "To Live and to Love on Mars" involving Ms. Mulyani and Dr. Rachelle Ornan-Stone, a researcher/designer at heart in Sales and Marketing at Boeing Commercial Airplanes, that gave those in the audience who dream of going into space one day hope that this might actually become reality for ordinary people. Others attended a presentation by Dr. Bruce J. Holmes, vice president and executive director, Skytelligence Group at SmartSky Networks, LLC, on connected cockpits and the future of apps for aviation.

The rest of the afternoon included a keynote presentation by Brien Seeley, MD, on regional sky transit (the future mass market for electric aircraft) and panel discussions with Dr. Bruce J. Holmes, Mark D. Moore, and Brien Seeley discussing what the future may hold for on-demand mobility and David Shaw, CEO and founder of Global Business Analysis/Cyber Security for Critical e-enabled Systems, on managing risk in a dynamic cyber environment. A discussion followed on cybersecurity in aviation with David Shaw and Russ Syphert, who recently joined Global Business Analysis after a 12-year career in the military that included work as an intelligence analyst at the National Security Agency. The 2016 technical symposium concluded with a keynote presentation by Kourosh Hadi, Boeing's director of Commercial Airplane Product Development, on the challenges and opportunities in commercial aviation innovation.

The program provided a full day of insights into the many ways in which innovations in aerospace in the Pacific Northwest are redefining technological boundaries, creating new and improved aircraft, and expanding exploration opportunities in all aspects of flight and space travel. Most of the presenters have been engaged in significant scientific research, the discovery of new inventions, or the development of innovative new concepts in aerospace. Further details about the 2016 symposium may be found at http://pnwaiaa.org/2016-technical-symposium/; the full program is available at http://pnwaiaa.org/wp-content/uploads/2016/11/2016_Technical_Symposium_Program.pdf.

The AIAA PNW Section is proud to see how this event has evolved. In 2007, a group of young professionals within the PNW Section decided to organize an event for our local membership that would encourage young people to pursue careers in aerospace, reinforce their enthusiasm, expand their horizons, and give the leaders in the industry a forum for sharing their knowledge and experience. Our first symposium was a two day event at the University of Washington, with Joe Sutter, the father of the 747, as our keynote speaker. While over the years the topics have become more diverse, with an increasingly significant role for the space industry, the intent of that first symposium continues as evidenced by the positive reactions of the more than 100 students and professionals who attended!

The section looks forward to the next edition of the PNW AIAA Technical Symposium, which will take place on 11 November 2017. We thank the many volunteers from the PNW-AIAA Council as well as this year's sponsors who made the 2016 symposium a reality for our AIAA membership.

Dr. Hanspeter Schaub Appointed As New Editor-In-Chief Of The *Journal Of Spacecraft And Rockets*

On 12 January 2017, AIAA President James Maser formally appointed **Dr. Hanspeter Schaub** as editor-in-chief of the *Journal of Spacecraft and Rockets* (*JSR*).

Dr. Schaub holds B.S., M.S., and Ph.D. degrees in Aerospace Engineering from Texas A&M University. Currently Schaub is the Alfred T. and Betty E. Look Professor of Engineering in the Ann and H.J. Smead Department of Aerospace Engineering Sciences at the University of Colorado Boulder. His research interests include spacecraft proximity flying, charged astrodynamics including touchless actuation of space debris, redundant attitude control using momentum exchange devices, autonomous attitude control and mission support, as well as astrodynamics software research tool developments. He is also the Director of the Autonomous Vehicle Systems Laboratory doing research in attitude control, as well as relative motion sensing and dynamics and control of aerospace systems. He is an AIAA Associate Fellow and a Fellow of the American Astronautical Society.

Dr. Schaub is an exceptional aerospace engineering researcher, educator, and leader. He is a prolific author of journal and conference papers, and he is the primary author, along with John Junkins, of the popular textbook, *Analytical Mechanics and Space Systems*, published in the AIAA Education Series and winner of the Summerfield Book Award. He has served as an associate editor for the *Journal of Guidance, Control, and Dynamics*, and other journals, and is an editorial advisory board member for the AIAA Education Series.

Hanspeter Schaub was selected from an exceptional pool of applicants, and becomes the tenth editor-in-chief of the journal. The *Journal of Spacecraft and Rockets* was among the journals established by AIAA in 1964, following the merger of the Institute of the Aerospace Sciences and the American Rocket Society, in an effort to ensure that significant application papers had an appropriate outlet for publication. Since its inception, *JSR* has filled a specific and continuing need in the community of aerospace-related archival journals. Schaub succeeds Dr. Robert Braun, who has served as editor-in-chief of *JSR* since 2014.

During the editor search process, one enthusiastic recommendation on Schaub's behalf noted that if selected for the position, his "exceptional professionalism, passion for his work, and dedication to the task will further enhance the reputation and impact of *JSR*." Looking toward the future, it is clear that Dr. Schaub's ability to think creatively and work collaboratively will serve to enhance the quality, rigor, and reach of *JSR*.

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– Margaret Cousins

For more information on nominations: www.aiaa.org/Honors

AIAA

2017 International Student Conference Winners

The AIAA Foundation International Student Conference takes place annually at AIAA SciTech Forum. Students who have won first place in the Regional Student Conferences have a chance to present their papers at a professional technical conference. The event is funded through the AIAA Foundation and offers the students a chance to showcase their research at an event where they can network with potential employers or colleagues. The 2017 International Student Conference was held on 10 January in conjunction with AIAA SciTech Forum in Grapevine, TX. Awards were given in 4 categories.

Graduate Division

Christopher Van Damme and **Matthew Allen**, University of Wisconsin – Madison (Region III), were awarded the prize for best overall student paper in the Graduate Division for their paper entitled "Evaluating Nonlinear Reduced Order Models' Ability to Predict Dynamic Snap Through of Curved Structures."

Undergraduate Division

Mia Lee, University of Washington (Region VI), was awarded the prize for best overall student paper in the Undergraduate Division for her paper entitled "Tunable Bistability of Origami-Based Mechanical Metamaterials."

Undergraduate Team Division

Darren Combs, Gabriel Frank, Sara Grandone, Colton Hall, Daniel Johnson, Trevor Luke, Scott Mende, Daniel Nowicki, and **Benjamin Stringer**, University of Colorado, Boulder (Region V), were awarded the prize for best overall student paper in the Undergraduate Team Division for their paper entitled "Project ELSA: Europa Lander for Science Acquisition."

Community Outreach Division

Ashley Scharfenberg and **Beth Dutour**, University of Alabama – Huntsville (Region II), were awarded the prize for the best overall student paper in the Community Outreach Division for their paper entitled "University of Alabama - Huntsville Community Outreach."

For more information on the AIAA Foundation International Student Conference, please contact Rachel Dowdy at 703.264.7577 or racheld@aiaa.org.

Left to right: Ron Barrett, chair of the Student Activities Committee; Christopher Van Damme, one of the Graduate Division winners; and Shelly Corbets, chair of the Student Paper Competition.

Left to right: Ron Barrett, chair of the Student Activities Committee; Mia Lee, Undergraduate Division winner; and Shelly Corbets, chair of the Student Paper Competition.

Left to right: Ron Barrett, chair of the Student Activities Committee; members of the winning Undergraduate Team Division; and Shelly Corbets, chair of the Student Paper Competition.

Left to right: Ron Barrett, chair of the Student Activities Committee; Ashley Scharfenberg, one of the Community Outreach winners; and Shelly Corbets, chair of the Student Paper Competition.

Lyne Wins First Place in IAC Student Conference

Christopher T. Lyne, from Vanderbilt University, Nashville, TN, and winner of the 2016 AIAA Foundation Abe M. Zarem Award for Distinguished Achievement in Astronautics, has also won first place in the Graduate Division of the 67th International Astronautical Congress (IAC) Student Paper Competition for his paper "Design and Test of a 10N Hydrogen-Peroxide Monopropellant Thruster."

"Our project focused on the design of a ten newton hydrogen-peroxide reaction control thruster, which was developed for attitude control in low altitude rocket flight for the 2016 NASA Student Launch," Mr. Lyne said. "I'm excited and humbled to receive the Pierre Contensou Medal for first place in this year's International Astronautical Congress student paper competition, as well as the Abe M. Zarem Award from AIAA earlier this year. I'm happy that a green thruster is coming back to prominence in today's world where renewability and sustainability are so important."

The Zarem award also recognized Mr. Lyne's faculty advisor, **Amrutur V. Anilkumar**, professor of practice of aerospace engineering and professor of practice of mechanical engineering at Vanderbilt University. Both Mr. Lyne and Dr. Anilkumar were honored during an awards luncheon at AIAA SciTech Forum in January.

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The Department offers M.S. and Ph.D. degrees in Aeronautical Engineering, Astronautical Engineering, Space Systems and Materials Science. The Department has several state-of-the-art computer and experimental laboratories. Interested candidates should send a resume and the names of three references to:

Dr. Brad S. Liebst, Professor and Head
Department of Aeronautics and Astronautics
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"You have the chance to affect things. Some ideas that I've seen have started in hallway conversations at AIAA forums… have gone far beyond anything I would ever believe."

—Rich Wahls, Strategic Technical Advisor, Advanced Air Vehicles Program, NASA Aeronautics Research Mission Directorate

AIAA

Shaping the Future of Aerospace

1917

Feb. 8 The Curtiss Co. unveils its Curtiss Autoplane at the Pan-American Aeronautical Exposition. It is a triplane with the body of a streamlined car of the day to reduce air resistance, and is powered by a four-bladed pusher type propeller from a Curtiss OXX 100-hp engine. It is called a "limousine of the air" and features upholstery and tapestries in the interior. **Aerial Age Weekly**, Feb. 19, 1917, p. 656.

1942

Feb. 1 The first combined American air and naval attack is made, using aircraft from the carriers USS Enterprise and USS Yorktown, against several Japanese installations on islands in the Marshall and Gilbert groups. A. van Hoorebeeck, **La Conquete de L'Air**, Vol. 2, p. 19.

Feb. 11 A Japanese aircraft drops notes addressed to the High Command at Singapore asking for the unconditional surrender of all military forces in Malaya. After ceaseless bombing by the Japanese, Singapore finally capitulates to the demands on Feb. 15, leading to the fall of Malaya. **The Aeroplane**, Feb. 20, 1942, p. 203, 219.

Feb. 14 The Douglas four-engined DC-4 Skymaster makes its first flight and subsequently revolutionizes long-range air transportation. The DC-4 becomes the backbone of civil aviation immediately after World War II and goes on to fame as the primary transport aircraft used by the U.S. Air Force and Navy during the Berlin Airlift of 1948-1949 that saved the city from starvation and further Soviet occupation. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 43.

Feb. 19 Australia is attacked for the first time in its history when Japanese bombers make two raids on Port Darwin. Of the 242 bombers engaged in these actions, only four are shot down. Some damage is caused to shipping and airplanes on the ground but no vital damage is done to military installations. **The Aeroplane**, Feb. 27, 1942, p. 229, 231.

Feb. 22 Maj. August von Parseval, the famous German aviation pioneer and creator of the Parseval non-rigid airship, dies in Berlin. In 1894, von Parseval, with 1st Lt. Bartsch von Sigfeld, demonstrated the first German kite balloon. In 1911, von Parseval organized the first German participation in the International Circuit of Europe on behalf of the German government. **Interavia**, Feb. 27, 1942, p. 11.

1967

Feb. 4 The European Space Research Organization begins the second of its series of sounding rocket launches from Kiruna in northern Sweden, starting with five French two-stage Centaur solid-propellant vehicles that carry experiments designed by scientific groups in Belgium, Denmark, West Germany, the Netherlands and Britain. The experiments are mainly studies of auroral phenomena. **Flight International**, Feb. 9, 1967, p. 218.

Feb. 4 The Lunar Orbiter 3, the third in a series of five unmanned spacecraft, is launched by an Atlas-Agena D from Cape Kennedy, Florida, to take high-resolution photographs of potential lunar landing sites for the upcoming Project Apollo manned lunar landing program. The spacecraft is also to improve our knowledge of the moon and monitor micrometeoroid and radiation intensities in the lunar environment. **New York Times**, Feb. 6, 1967, p. 12.

Feb. 6 Japan launches a three-stage Lamda 3H rocket from the Uchinoura Space Center, Kyushu Island, to a 2,142 kilometer altitude, a new record for a Japanese rocket. The 8,618 kilogram vehicle carries instruments to gather data on the Van Allen belts and the ionosphere at the peak of its flight. The 29-minute flight ends when the rocket's third stage impacts 2,253 km downrange in the Pacific. **New York Times**, Feb. 7, 1967, p. 27.

Feb. 8 The Saab Viggen (Thunderbolt) AJ 37 Swedish single-seat, single-engine, short-medium range combat aircraft takes off from the company's field at Linköping, Sweden, for its first flight. The Viggen is a multimission aircraft suitable for attack, fighter and reconnaissance missions. Subsequently, it becomes the first canard design produced in quantity with some 329 produced over the years. Powered by a Flygmotor RM8 turbofan engine, the Viggen enters service with the Swedish Air Force in 1971 and retires in 2005. **Aviation Week**, Feb. 27, 1967, p. 23; "Saab Viggen" file, NASM.

Feb. 10 West Germany's Dornier Do-31 14-T vertical takeoff and landing aircraft takes off from Munich on its first test flight. The Do-31 14-T, a test version of the Do-31E prototype VTOL, is lifted into a hovering mode by eight Rolls-Royce RB-162-4D and two Bristol-Siddeley Pegasus 5-2 turbojet engines. This test vehicle is not able to achieve forward flight but can hover free from ground restraints. **Aviation Week**, Feb. 20, 1967, p. 20.

Feb. 15 Biosatellite 1, launched on Dec. 14, 1966, re-enters from its orbit for recovery but its retro-rocket fails to fire. The satellite, carrying pepper plants, wheat seedlings, frog eggs, and amoeba and other organisms, is believed to descend in western Australia. The widespread search is canceled by NASA on Feb. 22. This is the first of three spacecraft in NASA's Biosat program that studied the effects of the space environment on organisms. **Flight International**, Feb. 22, 1967, p. 298; **Washington Post**, Feb. 23, 1967, p. A3.

Feb. 15 Lunar Orbiter 3's scanning system transmits the first high-resolution pictures to NASA's deep space tracking network receiving stations in Robledo, Spain, and Goldstone, California, of Primary Site 1, the relatively smooth Mare Tranquillitatis (Sea of Tranquility) area of the moon as a potential landing site for Project Apollo. On July 20, 1969, Apollo 11's Eagle Lunar Excursion Module, or LEM, achieves man's first lunar landing in this area. **Aviation Week**, Feb. 27, pp. 20-22.

Feb. 15 France's Diademe 2 geodetic satellite is launched by a three-stage Diamant rocket from Hammaguir, Algeria. This marks the last French launch from Algeria. Future launches of French satellites are to be carried out from the new base at Kourou, French Guiana. However, the 22.7 kilogram satellite reaches a lower orbit than planned and only achieves 60 percent of its geodetic measurement mission. This is France's fifth satellite — the fourth to be French-launched — and is equipped with crystal reflectors that return laser pulses from Earth for its geodetic measurements. **Aviation Week**, Feb. 20, 1967, p. 25 and Feb. 13, 1967, p. 41; **Flight International**, Feb. 23, 1967, p. 297.

Feb. 28 In a budget request to Congress, President Lyndon B. Johnson gives the go-ahead for $91 million to begin the construction of a nuclear rocket engine that could be used to power an upper stage of the Saturn 5 launch vehicle. The engine is a continuation of the joint Atomic Energy Commission/NASA Rover nuclear thermal rocket program. According to the budget request, the plans call for the delivery of the first test engine by about 1971. Ambitious interplanetary missions using the nuclear engine are envisioned, including manned missions to Mars. However, after considerable technical progress is made with nuclear-propelled test engines, mainly at Jackass Flats, Nevada, the Nuclear Engine for Rocket Vehicle Application or NERVA program suffers severe budget cuts in 1971 into 1972 that are exacerbated by the ending of Saturn 5 production. The NERVA program is consequently halted in January 1973. **Flight International**, March 9, 1967, p. 373; David Baker, **The Rocket**, pp. 209-210.

1992

Feb. 11 The U.S. Air Force launches an Atlas rocket with an undisclosed military satellite into orbit. It is designed to link the military with the president during a crisis; in peacetime it will connect military and civilian personnel in the Department of Defense. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 176.

Feb. 23 Using a Delta 2 booster, a Navstar global positioning satellite is placed into a circular 12-hour orbit, 20,100 kilometers above Earth. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 179.

JULIAN HORVATH, 31

Senior Engineer, Ground Systems and Mission Operations
Iridium Communications Inc.

No one has launched 10 satellites at once that are as sophisticated as the 860-kilogram spacecraft that Iridium Communications launched into low Earth orbit Jan. 14. "If you were to search for someone who has done something like that before," the closest would be Iridium, says Julian Horvath, who led Iridium's effort to prepare for the launch. In the late 1990s, the company then known as Iridium Satellite LLC launched seven communications spacecraft at a time while building the 66-satellite constellation that established the world's first global service for placing telephone calls and sending messages to pagers. It has now begun launching its 66-satellite Iridium Next constellation, which is designed to provide customers with far more bandwidth and higher data speeds. Horvath leads efforts to create a detailed checklist of everything that has to happen on the ground now that the first batch of satellites has been launched. This includes all the commands and procedures the Iridium team must follow to ensure that each of the new satellites moves close to one of the spacecraft currently in orbit and takes over its responsibilities without interrupting communications services for customers on the ground.

How did you move into this job?

It's what I always wanted to do. When I was little, my mom used to buy me Lego sets of pirate ships and I would build space ships. My mom yelled at me and made me build the pirate ship first. Then, I was allowed to take the pirate ship apart and build a space ship. I've always wanted to work in the aerospace industry. I was about to start school to get an aerospace engineering degree, but at the last minute there was a program that stole my interest. I ended up getting a degree in space physics with a concentration in exotic propulsion systems at Embry-Riddle Aeronautical University in Prescott, Arizona. In space physics and engineering, you learn how to do all the same math, so it's not hard to jump over. When I was getting done with my undergraduate degree, I wanted to work for at least a few years before going back to school. I've had good opportunities since then. I never thought about going back to school again.

What do you think will be going on in space in 2050?

I hope that we will be on Mars. I still hope and dream that I will get to go one day. But as far as our industry and Iridium is concerned, in 2050 I would expect continued growth in capabilities. There may be new exotic propulsion systems, but for the really fast ones, like antimatter, that is something we currently don't know how to do. But there are people researching it and eventually we will figure it out. We learned how to fly and we learned how to travel in space, so those other things will come in time. I hope that by 2050 with everything going on now, there will be more reusability for the rockets so space launches will be more affordable and it will be easier to launch satellites for companies like Iridium. ★

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